Center for
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RESEARCH REPORT

The Vehicle Speed Impacts of a Dynamic Horizontal Curve Warning Sign on Low-Volume Local Roadways

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CTS 12-12

Technical Report Documentation Page

1. Report No. CTS 12-12	2.	3. Recipients Accession No.
4. Title and Subtitle The Vehicle Speed Impacts of a Dynamic Horizontal Curve Warning Sign on Low-Volume Local Roadways		5. Report Date May 2012 6.
7. Author(s) Keith K. Knapp and Ferrol Robinson		8. Performing Organization Report No.
9. Performing Organization Name and Address Humphrey School of Public Affairs University of Minnesota 301 19th Ave. S Minneapolis, MN 55455		10. Project/Task/Work Unit No. CTS Project #2009058 11. Contract (C) or Grant (G) No. (c) 89261 (wo) 146
12. Sponsoring Organization Name and Address Minnesota Department of Transportation 395 John Ireland Boulevard, MS 330 St. Paul, Minnesota 55155		13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code
15. Supplementary Notes http://www.cts.umn.edu/Publications/ResearchReports/		

16. Abstract (Limit: 200 words)

This research project evaluated the vehicle speed impacts of a dynamic curve warning sign (DCWS) at three study sites on low-volume, local rural highways. Vehicle speed data were collected one month before and one month, six months, one year, and 18 months after the installation of a DCWS at the visually identified point of curvature (PC).

Data were collected at three locations within each study site. These locations were the PC, within the curve, and at an approach tangent control. Before and after differences in average speed were calculated for vehicles traveling into the horizontal curve. The overall range of differences in the unadjusted average vehicle speeds at the PC was -8.8 mph to -1.0 mph. This range changes to -8.6 mph to +1.9 mph after a naive adjustment of these differences for the average vehicle speed changes at the control locations.

It was concluded that the DCWS appeared to have larger impact at horizontal curves with lower advisory speeds and on the number of higher speed vehicles. It is recommended that the installation of DCWSs on low-volume roadways be considered on a case-by-case basis and that a lower-cost version of the sign evaluated be explored.

17. Document Analysis/Descriptors Highway safety, Low volume roads, Variable message signs, Traffic speed, Highway curves, Playgrounds		18. Availability Statement No restrictions. Document available from: National Technical Information Services, Alexandria, Virginia 22312	
19. Security Class (this report) Unclassified	20. Security Class (this page) Unclassified	21. No. of Pages 96	22. Price

The Vehicle Speed Impacts of a Dynamic Horizontal Curve Warning Sign on Low-Volume Local Roadways

Final Report

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May 2012

Published by:

Center for Transportation Studies
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200 Transportation and Safety Building
511 Washington Avenue SE
Minneapolis, Minnesota 55455

This report represents the results of research conducted by the authors and does not necessarily represent the views or policies the Federal Highway Administration, the Minnesota Department of Transportation, or the Center for Transportation Studies. This report does not contain a standard or specified technique

The authors, the Minnesota Department of Transportation, and the Center for Transportation Studies do not endorse products or manufacturers. Any trade or manufacturers' names that may appear herein do so solely because they are considered essential to this report.

Acknowledgements

The financial, logistical, and/or technical support provided by the Minnesota Department of Transportation, the Federal Highway Administration, and the State and Local Policy Program at the Humphrey School of Public Affairs - University of Minnesota is gratefully acknowledged. The active input and participation of the county engineers and staff in Meeker and McLeod counties was also essential to the completion of this project.

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Executive Summary

The majority of vehicle crash fatalities in the United States occur in rural areas. Horizontal curves on two-lane rural roadways are locations where a large portion of these crashes occur. In addition, vehicle speed is a factor in many of these crashes. This research project evaluated the potential vehicle speed impacts of a dynamic curve warning sign (DCWS) at three local rural, low-volume roadway locations in Minnesota. Two of the DCWSs were installed along county roadways in Meeker County and one in McLeod County. This project was designed to supplement and/or expand upon the work being completed as part of an ongoing national dynamic speed feedback sign (DSFS) demonstration study. The study design, criteria, and protocols used in the national DSFS demonstration study were, as appropriate, applied within this research project.

There has been a significant amount of research completed in the past that focused on the relationships between horizontal curve geometrics and vehicle speed or crashes. Some of the more critical horizontal curve characteristics that appear to impact vehicle speed are radius, superelevation, and approach tangent vehicle speed. The difference in the approach speed and the vehicle speed needed to properly negotiate a horizontal curve is also an important indicator of its potential level of safety. The crashes that occur on horizontal curves also appear to be related to its length, radius, and the existence of a spiral design. Several studies have considered the speed impacts of various dynamic warning sign designs. The studies that appeared to be most relevant to this project showed vehicle speed reductions attributed to the dynamic signs of zero to 7 mph. Several studies have also shown a reduction in crashes due to dynamic warning sign systems. No studies were found, however, that specially documented a focus on study sites along low-volume, local rural roadways.

The first step in the study design for this project was the selection of study sites. A large group of horizontal curves were considered as candidate study sites in Meeker and McLeod County. The databases used to identify the candidate study sites were created from a proactive horizontal curve safety improvement prioritization process. A significant number of horizontal curves in each county were prioritized as high, medium, and low for proactive safety improvements. The candidate study sites for this research project were those assigned a high or medium priority. Crash data was only one factor considered in this process. Two of the other factors used were the radii of the horizontal curve and the existence of a visual trap. The characteristics of the candidate study sites were then evaluated to determine their viability for this research project. Two physical characteristics required for a viable study site were that it be a two-lane roadway in a rural area. A traditional warning sign was also required because the DCWS was to be installed as a supplement. Four to six potentially viable horizontal curve approach study sites were selected as finalists from this activity and vehicle speeds at their visually identified point of curvature (PC) collected. The PC was also the DCWS installation site location. A required vehicle speed characteristic for a viable study site was that the mean or 85th percentile vehicle speeds at the visually identified PC meet the definition of a "location with potential speed concerns" used by the national DSFS demonstration study (i.e., mean or 85th percentile vehicle speeds 5 miles per hour or more above the posted or advisory speed limit). The study sites selected were on CSAH 25 and CSAH 3 in Meeker County and CSAH 7 in McLeod County.

The second and third steps in the study design for this project were the selection of a DCWS and its installation. The selection of the DCWS was simplified because one objective of this project was to follow the protocols and possibly combine results with the national DSFS demonstration study. The DCWS evaluated in this research project, therefore, had to be one the national DSFS demonstration study had also selected. Overall, two signs were selected for evaluation by the national DSFS demonstration study team and the Minnesota project team decided to install the curve display sign. This sign is the DCWS shown in Figure 4.1 of this report. Three DCWSs were installed by the county highway departments in May 2010 as part of this project. Many of the challenges encountered during the installation were related to the equipment needed and the lack of experience all local transportation agencies would have with this type of installation and the support structure selected. All pre-installation challenges, however, were overcome. Post-installation, unfortunately, the sign posts at two of the three study sites appeared to separate from their bases and the signs fell to the ground. This occurred at the first study site during an unusual weather event, but in the second case it was during what might be considered to be a typical high wind event in central Minnesota. The first sign fell just before a data collection time period and the impacts of its reinstallation are described in this report. The second sign fell after the last data collection activity for this project and did not impact its results. It is recommended that the sign support structure applied in this research project, when used in similar circumstances and with the DCWS considered here, be evaluated very closely. Alternative sign support structures are available.

The last step in this research project was the summary and analysis of the vehicle speed data collected. Vehicle speed data were collected at three locations within each study site: the visually identified PC (which is also the installation site location of the DCWS), within the curve, and a control (typically ¼ to ½ mile from the visually identified PC). Vehicle speed descriptive statistics were summarized for both directions of travel at each data collection location and the trends in average and 85th percentile vehicle speeds described. The focus of the data analysis, however, was on the differences in average vehicle speed for traffic flow toward the DCWS and into the horizontal curve. Average vehicle speeds at the visually identified PC and "within curve" locations one month before and one month, six months, one year, and 18 months after the DCWS installation were compared. A similar comparison was also done for the data collected at the control location. The statistical significance of the differences was determined through the application of a simple t-test. The impacts of a naïve adjustment to these differences based on the average vehicle speed changes observed at the control location are also described. This adjustment assumes that the changes observed at the control location are representative of background shifts in vehicle speed that can occur from one data collection time period to another.

The differences calculated in average vehicle speed before and after the installation of the DCWS at each study site are summarized in detail within this report. As noted above, the focus was on the data collected at the visually identified PC and "within curve" locations. Unadjusted and adjusted (for the shifts in average vehicle speed observed at the control location) differences in average vehicle speed are both summarized. These differences for the visually identified PC at each study site are noted below. The reader is referred to the report text for a discussion related to the "within curve" locations. The overall average of the "before and after" differences in average vehicle speed (for all the data collection time periods) at the visually identified PC

location of the CSAH 25 study site was -1.9 mph. This same measure was -7.0 mph at the CSAH 3 study site and -3.0 mph at the CSAH 7 study site. If these overall averages are naively adjusted for the shifts in average vehicle speed observed at the control locations, however, they change to -2.5 mph at CSAH 25, -5.2 mph at CSAH 3, and -2.6 mph at CSAH 7. The "before and after" differences in average vehicle speed calculated for the last data collection time period (i.e., 18 months after the DCWS installation) are also informative. The unadjusted and adjusted average vehicle speed differences at the visually identified PC of the CSAH 25 study site were -1.0 mph and -3.0 mph, respectively. It is important to note, however, that this was also the study site where the DCWS fell, and these vehicle speeds were actually collected only seven months after the reinstallation. Six months after the initial installation of the DCWS at the CSAH 25 study site the unadjusted and adjusted average vehicle speed differences at the visually identified PC were -3.1 mph and -3.0 mph, respectively. Similar calculations of the unadjusted and adjusted differences in average vehicle speed (for the last data collection time period) at the CSAH 3 study site indicate a reduction of -5.5 mph and -8.6 mph, respectively. These measures are -2.2 mph and +1.9 mph, respectively, at the CSAH 7 study site.

The percentage of vehicles traveling at least 5, 10, 15, and 20 mph faster than the posted or advisory speed limit at each study site was also analyzed for each before and after time period comparison. The average overall percent change at each study site generally showed that the impact of the DCWS appears to be proportionally larger on vehicles traveling at higher speeds. In other words, the number of vehicles traveling at higher speeds seems to be reduced proportionally more than those traveling closer to the posted or advisory speed limits. These higher speed vehicles are also those that are more likely to run off the road at a horizontal curve. A brief summary of the crash data before and after the installation of the DCWS at the study sites was also completed, but an analysis of these data was dropped from the project tasks. The reasons for this removal are explained. The before and after crash data provided in this report for the study sites are included only for use by the national DSFS demonstration study team if its application is helpful. In general, there were zero crashes during the three years before the installation of the DCWS at each study site and also for 19 months after the signs were installed. It is important to recall that crash data was only one factor considered in the proactive safety improvement prioritization process used to select the study sites. The five years of data considered in this process were also not the same as the three-year time period before the installation of the DCWSs.

This report concludes with a summary of overall project findings and recommendations. The findings are generally described above, but it does appear that the vehicle speed impacts of the DCWS were greater at the study site with the lowest posted advisory speed limit and that there was larger impact on higher-speed vehicles. In general, however, the findings of this project are limited by the small number of study sites considered. Therefore, it was recommended that the results be combined, if appropriate, with those from the national DSFS demonstration study. The vehicle speed impacts of DCWSs at more low-volume, local rural roadway study sites could also be considered. Overall, it is recommended that the implementation of DCWS on low-volume roadways be considered on a case-by-case basis, that the use of the sign support structure in circumstances similar to this research project be evaluated very closely (alternatives do exist), and that a lower-cost version of the DCWS considered in this research be considered to allow for more widespread use on low-volume, local rural roadways.

Chapter 1. Introduction

Warning signs are installed to provide information to vehicle drivers about hazards that may impact their decision-making. In general, these signs are located and designed to elicit one or more driver responses (e.g., more awareness, speed reduction). Warning signs are also sometimes supplemented with advisory speed limit signs.

Traditional warning signs are generally static in design. In other words, they send the same message to all drivers whether the hazard continually exists or not (e.g., traditional deer crossing warning signs when no animals are present) or whether a particular vehicle may be more at risk of encountering the hazard (e.g., traditional curve warning signs and an approaching vehicle traveling at a high rate of speed). This research project focused on the potential vehicle speed impacts of dynamic horizontal curve warning signs (DCWSs) on local rural, low-volume roadways in Minnesota. Vehicle speeds were used as the primary measure of DCWS effectiveness and a surrogate for safety at the study sites.

Problem Addressed

The rural roadway crash fatality rate in the United States is more than twice that of urban facilities. This difference in fatality crash rates is also found in Minnesota. An analysis for *NCHRP 500 Volume 7 - A Guide for Reducing Collisions on Horizontal Curves* also showed that about 25 percent of the roadway fatalities in the United States occurred along horizontal curves and approximately 75 percent of those were rural and/or single vehicle run-off-the-road incidents (*1*). Glennon, et al. also showed that horizontal curves had a crash rate that was about three times greater than tangent sections (*2*).

In Minnesota approximately 32 percent of the roadway fatalities from 2001 to 2005 were due to road departure crashes. The critical nature of this issue is especially apparent in the rural areas of the state (i.e., outside the Minneapolis/St. Paul Twin Cities metropolitan area) where the percent of fatal crashes related to lane departures appears to be greater than 50 percent (*3*). Approximately two-thirds of the fatalities outside the Twin Cities area occur along two-lane roadways (*3*). In addition, approximately 27 percent of the crash fatalities reported in Minnesota between 2001 and 2005 were on curves (*3*). Horizontal curves, however, represent only a small percentage of the roadway mileage in the system. It has also been shown that a large percentage of speeding-related fatalities occur on curves (*4*). Any plan to improve the safety of rural roadways must address the vehicle speeds selected by drivers as they approach and navigate horizontal curves. The research project described in this report included the collection and comparison of vehicle speeds before-and-after the installation of three DCWSs on three local rural low-volume roadways.

Project Scope and Objectives

The scope of this research project was limited to the evaluation of potential vehicle speed impacts related to one type of DCWS. This DCWS was installed at three rural low-volume roadway locations in Minnesota. Two of the DCWSs were installed along county roadways in Meeker County and one in McLeod County. Originally, it was also proposed that a before-and-after comparison of crash data at each study site would also be completed (and at similar control

sites). However, due to the low-volume characteristics of the roadways being considered, a crash occurring in the past at a horizontal curve was only one of the factors used in the selection of the study sites (see Chapter 3 for a detailed description of the study site selection process). The number of crashes at any particular horizontal curve was very small (e.g., between zero and 1 per year). Therefore, it was determined that a comparison of crash data before-and-after the installation of the DCWSs was not inappropriate (see Chapter 5 for more information about this decision). Shifts in vehicle speed before-and-after the installation of a DCWS were examined instead and used as a surrogate measure of horizontal curve safety. This project was also proposed as a supplement and expansion to an ongoing national dynamic speed feedback sign (DSFS) demonstration study. The study design, criteria, and protocols used in the national DSFS study were, as appropriate, applied within this research study.

The primary goal of the research project described in this document was the evaluation of potential vehicle speed impacts (and inherent safety impacts based on these speed changes) at three DCWS installations in Minnesota. The project objectives included:

- Coordination with Iowa State University with respect to the criteria, protocols, sign vendor, and current schedule of the ongoing national DSFS demonstration study.
- Application of an appropriate study site selection methodology that results in three horizontal curve locations that have speed and/or safety concerns along low-volume rural county roadways in Minnesota.
- Application of a DCWS selection methodology and the installation of DCWSs at three Minnesota locations.
- Collection, summary, and analysis of the vehicle speeds collected before-and-after the installation of the DCWSs. The direct evaluation of crash data before-and-after the installation of the DCWS, however, was eliminated from the project scope (see the explanation above and in Chapter 5).
- Documentation of the project results with a focus on the potential vehicle speed impacts due to the DCWSs at the study sites. The characteristics of the study sites, however, did not allow the segregation of the vehicle speed data into different vehicle classifications. The low volumes at the study sites for this project make this type of comparison difficult.

Report Organization

There are six chapters to this project report. Chapter 1 describes the problem addressed, the scope, and the objectives of the overall research project. Chapter 2 includes a summary of relevant literature. The general results of published research studies that focus on the relationships between horizontal curve geometrics, safety, and speed are described. Existing publications that describe research projects that explore the impacts of traditional horizontal curve warning signs and various dynamic warning signs are also summarized. Chapter 3 describes the site selection methodology applied during this project and its results. Chapter 4 includes a summary of the sign selection process used and its results. In addition, the challenges and lessons learned during the installation process are described. Chapter 5 describes the approach used to collect vehicle speeds at each study site. It also includes a summary and comparison of the vehicle speed data collected before-and-after the installation of the DCWSs.

Finally, Chapter 6 provides a summary of the overall study findings and a list of recommendations based on the results of the research project activities.

Chapter 2. Literature Summary

This chapter summarizes the literature reviewed as part of this research project. A brief description of the most current and comprehensive state-of-the-knowledge documents relevant to this project is included. The sections of this chapter focus on the following subjects:

- Horizontal curve geometrics and safety,
- Horizontal curve geometrics and speed, and
- Traditional and dynamic warning sign impacts.

In 2002 approximately 25 percent of fatal crashes in the United States occurred at horizontal curves (*1*). In fact, past research has also shown that the average curve crash rate is about 3 times greater than that occurring along tangents (*1*, *2*). In addition, sharper curves have higher crash rates than those with longer radii (*5*). Overall, almost three quarters of the fatal horizontal curve crashes that occurred within the United States in 2002 were also in rural areas and about the same percentage of these crashes were single-vehicle run-off-the-road incidents (*1*).

Many lane departure and/or single vehicle run-off-the-road crashes occur on or near horizontal curves. From 2001 to 2005 approximately 32 percent of the roadway fatalities in Minnesota were single vehicle run-off-the-road incidents (*3*). In addition, more than 50 percent of the fatalities in the rural Minnesota (i.e., outside the Twin Cities metropolitan area) were due to lane departures (*3*). This percentage increases to more than 60 percent along local rural roadways in Minnesota (*3*). Overall, county roadways in Minnesota experience almost half the annual roadway fatalities in the state and have a fatal crash rate that is 20 percent greater than similar roadways within the state highway system (*3*).

Horizontal Curve Geometrics and Safety

A large number of research projects have either focused on the potential reason(s) crashes occur at or near horizontal curves or evaluated proposed crash countermeasures (e.g., adding chevrons, curve flattening, etc.). Several references contain summaries of many of these studies (*1*, *5*, *6*). Some of the characteristics these past studies have found impact the safety of horizontal curves include (*5*):

Traffic volume and mix (e.g., percent trucks);

- Curve features (e.g., degree of curvature, length, central angle, superelevation, and/or presence of a spiral);
- Cross section features (e.g., lane width, shoulder width, shoulder type, and/or shoulder slope);
- Roadside hazard (e.g., clear zone, sideslope, rigidity and/or type of obstacles);
- Stopping sight distance on curve or curve approach;
- Vertical alignment;
- Distance to adjacent curves;
- Presence/distance to nearest intersection, driveway, bridge, etc.;
- Pavement friction; and
- Presence/type of traffic control devices (e.g., signs and delineation).

The focus of this literature summary, however, is the research that considered the roadway geometrics that may impact horizontal curve safety.

The Federal Highway Administration (FHWA) developed a decision-making tool that can be used to estimate the safety and operational impacts of geometric design decisions along two-lane rural roadways (see http://www.fhwa.dot.gov/research/tfhrc/projects /safety/comprehensive/ ihsdm/). This tool is called the Interactive Highway Design Model (IHSDM). In 2000 the methodology that generally formed the basis of the IHSDM crash prediction module was published (*6*). The base model for crash prediction proposed in this document includes a variable related to horizontal curves (*6*). The results of this model must be adjusted for the existing and/or proposed geometric design elements of the roadway segment being evaluated. This adjustment is done through the application of one or more accident modification factors (AMFs). AMFs greater than 1.0 indicate the geometric feature increases the number of predicted crashes (*6*).

The AMF for horizontal curves includes length, radius, and spiral presence as inputs (*6*, *7*). It generally increases as horizontal curve length increases and decreases as radius increases and a horizontal curve approach spiral is introduced (*6*, *7*). In other words, the number of predicted crashes per year along a roadway segment will generally increase with horizontal curve length, reductions in horizontal curve radii, or the removal of horizontal curve spirals (*6*). An AMF was also proposed for horizontal curve superelevation deficiencies (*6*). This AMF increases the number of crashes predicted as the deficiency increases (*6*).

Some new horizontal curve related crash prediction research has also recently been published (*8*, *9*). In 2009 Easa, et al. proposed several crash prediction models that attempted to take into account situations involving the three-dimensional nature of roadway curves (*8*). The models developed were based on Highway Safety Information System (HSIS) crash data for curved roadway segments with various horizontal and vertical characteristics or components (*8*). The horizontal curve characteristics that were represented by variables in the final crash prediction models included degree of curvature and length (*8*). It should be noted that curve radii is inversely related to and decreases with degree of curvature. The results of this study generally agreed with those previously described. The frequency of crashes predicted to occur along a roadway segment increased with degree of curvature and curve length (*8*). Models for truck

crashes along horizontal curves were also recently developed by Schneider, et al. (*9*). These models included length of curve and degree of curvature as statistically significant variables, and, not surprisingly, the number of truck crashes predicted increase with both (*9*). Milton and Mannering also found that shorter tangent lengths between horizontal curves were associated with smaller crash frequencies (*10*).

Horizontal Curve Geometrics and Speed

The FHWA estimates that more than half of the crashes that occur on horizontal curves are speed related (*3*). Research has also shown that the difference in vehicle speed between a tangent and horizontal curve is also related to the magnitude of expected crashes at this interface and can be used as a surrogate measure for that issue (*11*, *12*). Larger speed reductions at horizontal curves can result in a higher number of crashes (*12, 13, 14, 15*). The speed selected by a driver before entering a horizontal curve has an impact on his or her ability to negotiate the change in alignment (*16*). Preston, et al. found, based on the evaluation of vehicle speeds at a horizontal curve with a DCWS, that drivers traveling at or below the speed limit were significantly more likely to properly negotiate the curve than those traveling above the speed limit (*16*).

The IHSDM analysis tool developed by FHWA includes a design consistency module that uses speed-profile models to identify and "flag" potential differences in vehicle speed along two-lane rural roadways. These models estimate the 85th percentile free-flow passenger vehicle speed profile (using several different approaches) along existing or proposed two-lane rural roadways. The IHSDM can then identify or "flag" speed consistency concerns where there are large differences between the 85th percentile speeds between adjacent roadways segments or the 85th percentile speeds and the assumed design speed. Significant speed differences, a particular focus in the IHSDM calculations, can occur at horizontal curves.

The basis of the speed estimates used in the IHSDM was a large research project that had its results published in 2000 (*11*). This project was completed to expand upon an earlier design consistency study by Krammes, et al. and it created a series of speed prediction equations and methodologies for use in speed-profile modeling (*11*, *17*, *18*). These research results were based on vehicle speed data from more than 200 curves in six states and produced several models to estimate 85th percentile horizontal curve vehicle speeds (*11*, *18*). However, although a number of geometric characteristics were considered, each model only included horizontal curve radius as the primary variable (*11*, *18*). Different models were then produced for horizontal curves that interacted with vertical grade situations. For example, there were speed models for horizontal curves on negative grades between -9 and -4 percent, -4 and 0 percent, 0 and 4 percent, and 4 and 9 percent (*11*, *18*). Overall, and not surprisingly, the horizontal curve 85th percentile speed predicted by these models generally increases with the radius (*11*, *18*). In addition, it was also concluded that the data showed that the operating speed on horizontal curves with a radius of approximately 2,625 feet (800 meters) or more were very similar to those along long tangents (*11*, *18*). Vehicle speeds on the horizontal curves decreased quickly, however, when the radius was less than approximately 820 feet (250 meters) (*11*, *18*).

The speed profile models describe above can be used within the IHSDM to assist with horizontal curve geometric design (*11*, *18*). For example, the IHSDM can be told to produce a green flag for predicted differences in 85th percentile tangent and horizontal curve speeds of 6 miles per

hour (mph) (10 kph) or less, a yellow flag for differences of 6 to 12 mph (10 to 20 kph), and a red flag for differences of greater than 12 mph (20 kph) (*11*, *17*, *18*). These are referred to as "good", "fair", and "poor" design in an example provided by Fitzpatrick, et al. (*11*, *18*).

The kinematics equation from the AASHTO "A Policy on Geometric Design of Highways and Streets" for horizontal curve speed includes side friction, superelevation, and radius as variables (*19*). The horizontal curve speed produced with this equation increases with all three of these variables. Other research projects, as reviewed by Bonneson, et al and Fitzpatrick, et al., have also shown that the following variables also impact horizontal curve speed (*11*, *18*, *20*):

- Tangent speed,
- Vehicle type,
- Horizontal curve deflection angle,
- Horizontal curve length,
- Available stopping sight distance,
- Grade, and
- Vertical Curvature.

Bonneson, et al. recently completed a study that focused on rural horizontal curve speed prediction (*20*). Their results and approach, however, were somewhat different then that used by Fitzpatrick, et al. (*11*, *18*, *20*). Fitzpatrick, et al. created horizontal curve speed prediction models for different vertical grade situations and they included radius as the only model variable (*11*, *18*). The 85th percentile curve models produced by Bonneson, et al., on the other hand, were developed for several tangent approach speeds and included a number of variables (*20*). Bonneson, et al. (and other researchers) have concluded that approach speed had a strong influence on horizontal curve speed choices (*20*). They also determined that drivers appear to adjust or modify their side friction demands with horizontal curve geometry or speed (*20*). Drivers appear to have lower demands on side friction at more gradual (i.e., larger radius) higher-speed horizontal curves and are willing to accept a higher side friction on sharper curves (*20*). It was also concluded that the impact of superelevation on horizontal curve speed was not as important as radius and approach speed (20).

Overall, the parabolic horizontal curve speed prediction model proposed by Bonneson, et al. includes superelevation, radius, and tangent approach speed as inputs (*20*). The 85th percentile horizontal curve speed predicted by the model increases with radius for a given superelevation and 85th percentile tangent speed (*20*). It was found, however, that the prediction capability of the model also improved when the actual radius of the "vehicle path" was used rather than the designed or constructed horizontal curve roadway radius (*20*). The actual path of a vehicle along a circular curve is more of a spiral and vehicles shift toward the roadway centerline (*20*). The Bonneson, et al. model did not include the impacts of vertical grade (similar to the Fitzpatrick, et al. study described previously) because their database did not include horizontal curves with a wide range of these characteristics (*11*, *18*, *20*).

Horizontal Curve Warning Sign Impacts

Traditional Horizontal Curve Warning Signs

In 2004 NCHRP Report 500 (Volume 7), "A Guide for Reducing Collisions on Horizontal Curves", was published (*1*). The authors of this document summarized the speed and/or crash results of several research projects focused on the implementation of traditional horizontal curve warning signs and/or horizontal curve speed advisory signs (*1*). The results of these studies varied. Some of the studies found no impact from the signs on vehicle speed choice by drivers along horizontal curves and one study even found an increase in vehicle speed after the sign implementation (*1*). Only one of the studies that was referenced, however, attempted to evaluate the crash impacts of implementing horizontal curve warning signs and/or horizontal curve advisory speed signs (*1*). This study concluded that the installation of horizontal curve warning signs decreased crashes by 18 percent and that the installation of warning signs and advisory speed signs decreased crashes by 22 percent (*1*). Although it is not properly referenced, this same study also appears to be briefly discussed in the American Traffic Safety Services Association (ATSSA) "Low Cost Local Road Safety Solutions" document (*21*).

A more recent study on the safety impacts of signing improvements was also summarized in the document entitled "Low Cost Local Road Safety Solutions" (*21*, *22*). The signing program in Mendocino County, CA included the improvement of signing deficiencies and the use of high intensity retroreflective sheeting (*21*, *22*). The focus at the start of the program was to improve horizontal curve signing and eliminate nonstandard signing (*21*, *22*). Between 1992 and 1998 the crashes along the 19 roadways reviewed and improved were reduced by 42 percent, fatalities were down by 61 percent (n = 13 to n = 5) and injuries decreased by 42 percent (*21*, *22*). The crashes along non-reviewed and non-improved county roadways, however, increased by approximately 27 percent and the crashes along the state highways in the county decreased by about 3 percent (*21*, *22*). Not all of the signs replaced, of course, were related to horizontal curves, but it is likely that their implementation helped produce these results.

In addition, in September 2007 the FHWA also published the "Desktop Reference for Crash Reduction Factors" (*23*). This document attempted to summarize research that defined the crash reductions expected if certain countermeasures were implemented. A large number of crash reduction factors related to roadway departure crash countermeasures were summarized (*23*). However, the document included factors based on both nationally respected research studies and those that have results with a reliability considered to be "…low or very low" (*23*). The application of this guide, therefore, still required some engineering judgment (*23*). Overall, four references were summarized in the desktop reference that appeared to be related to the installation of horizontal curve warning signs (*23*). The research results summarized appear to show an 8 to 55 percent reduction in various crash types (e.g., all and run-off-the-road) and severities (i.e., property damage, injury, and/or fatalities) due to the installation of these signs (*23*). The more typical range of these crash reductions, however, appears to be between 20 and 30 percent (*23*). The results documented for situations when the horizontal curve warning signs are installed with a speed advisory sign, on the other hand, appeared to show a crash reduction between 13 and 29 percent (*23*). The authors of NCHRP Report 559, "Communicating Changes in Horizontal Alignment", indicate that the literature, although varied on this subject, includes

some studies that do show a reduction in single vehicle and run-off-the-road crashes when advisory horizontal curve warning signs and/or advisory speed signs are installed (*24*).
It is also important to note that since the publication of the desktop document described above a website that ranks the statistical robustness of crash reduction or modification factors has been introduced (www.cmfclearinghouse.org) and the "Highway Safety Manual" has been published (25). Both these resources are now critical in the determination of the safety impacts related to roadway improvements (*25*).

Even more recently Dixon, et al. developed a model that defined a relationship between advisory speed signs and safety (*26*). The model included a series of geometric, operational, and signing factors, and the research team concluded that the existence of an advisory speed plaque influenced safety (e.g., crashes), but that it was small in comparison to some of the other factors mentioned in this literature summary (e.g., volume, horizontal curve length, and horizontal curve radius). A methodology was developed to assist with the posting of advisory speed plaques. This methodology was based on the model developed, but the results were advisory speed plaques within 5 mph of the method proposed in the MUTCD (*26, 27*). The research team recommended their approach to the posting of advisory speed plaques because it produced more consistent applications (*26*). Their method was also the only approach evaluated that suggested the implementation of advisory speeds at sites with a crash history. In other word the approach took crashes into account.

Dynamic Horizontal Curve Warning Signs

NCHRP Report 500 (Volume 7) also included a summary of some various DCWS studies and their results (*1*). Many of these types of signs have been installed to reduce the number of truck rollover incidents at very sharp curves (e.g., freeway ramps). For example, the NCHRP Report 500 (Volume 7) authors summarize an evaluation of the impacts related to the installation of truck rollover warning signs at three ramps in Virginia and Maryland (*1*). The study results showed that 10 rollover crashes had occurred before the installation of the system and no crashes occurred during the three years after (*1*). A summary of the speed data collected by the researchers also showed that the speed selection by "high-speed" trucks were reduced to a greater extent when the signs were activated than when they were not (*28*). Overall speed reductions of approximately 20 to 30 percent (or 1.4 to 2.9 mph) appear to have occurred after the installation of the signs (*28*).

A study that focused on the potential impacts related to DCWSs at five locations along the California interstate system was also summarized in NCHRP Report 500 (Volume 7) (*1*, *29*). These signs warned people of the curve ahead (and its advisory speed) and also indicated the actual speed of the vehicle (*1*). Overall, significant truck speed reductions (near the beginning of each curve) were found at three of the five curves after the installation of the signs and passenger vehicle speed reductions were observed at two of the five curves (*1*, *29*). One of the curves only experienced a truck speed reduction during the initial data collection period (*29*). These speeds increased during subsequent data collection activities (*29*). Overall, little additional explanation is provided about the reasons that might indicate why there was a lack of consistency in the speed results (*1*, *29*). The report for this project was published in 2000 and was done too quickly after the sign installations to complete a statistically significant analysis of crash data (*1*, *29*). The crash impacts for a dynamic curve warning system installation along the California

interstate, however, was also summarized (although not properly referenced) in the 2006 FHWA "Low Cost Treatments for Horizontal Curve Safety" report (*30*). This report indicated that crashes were reduced by 44 percent during the first year after installation and 39 percent lower during the second year (*30*). It is unknown whether the California systems summarized in NCHRP 500 (Volume 7) and the FHWA document are the same installations (*1*, *30*).

A study similar to that described above was also completed by Bertini, et al. (*31, 32*). This study focused on the potential impact of a dynamic curve warning system along Interstate 5 in Oregon. This system displayed several different messages to drivers based on their choice of approach vehicle speed (e.g., "caution", "slow down", "sharp curves ahead", "your speed is XX mph") (*31, 32*). The study project team evaluated the change in mean vehicle speed for both passenger cars and trucks, the change in speed profiles for these vehicles, and the public response to the signs (*31, 32*). Speed data were collected for four days before the installation of the signs and for three days after. Overall, it was concluded that the dynamic curve warning system reduced the mean vehicle speeds for passenger cars and trucks by 2 to 3 mph (*31, 32*). The vehicle speed profiles also changed after the installation of the dynamic curve warning system. It was generally found that fewer vehicles were traveling at higher speeds (*31, 32*). A surveys of drivers at a nearby rest area also indicated that their perception of the system was positive (*31, 32*).

In the late 1990s a DCWS (displaying "curve ahead" or "curve ahead" and "reduce speed" in sequence) was installed along a Minnesota county roadway adjacent to a traditional horizontal curve warning sign (with a 40 mph advisory speed) (*16*). Vehicle speeds and other horizontal curve negotiation performance measures (through the use of a video camera) were collected during a four day period to evaluate the sign impacts. Data were only collected for vehicles traveling at or above 53 mph (the meaning of this vehicle speed was not documented) and the sequential sign message noted above was randomly assigned to these vehicles (otherwise just the "curve ahead" message was presented to the driver) (*16*). Vehicle speed data were collected on more than 2,600 vehicles and the navigation analysis was completed for 589 vehicles randomly selected from this database (*16*). It appears that the vehicle speeds for this project were collected approximately 700 feet upstream of the warning sign and then every 3 seconds while the vehicle remained in the radar field of view (the radar was located at the dynamic and static curve warning signs installation site) (*16*). Overall, the average speed decreased 12.1 and 12.3 mph for the "curve ahead" and sequential sign messages, respectively (*16*). The combination of a static sign with a blank DCWS, however, also appeared to result in an average decrease of 11.5 mph (*16*). The speed reductions observed (when the sign was active) were greater (up to 5 mph) for "higher-speed" vehicles traveling 60 mph or higher (*16*). The videotape camera data also showed that the navigation of the horizontal curve improved when sequential sign was activated (*16*). The latter impact was not observed when the DCWS only presented the "curve ahead" message (*16*). A successful navigation was assigned to a vehicle if it stayed within the lane lines (*16*). Overall, it was concluded by the researchers that the impact of the sign was "relatively small", but that its impact on high-speed vehicles (those most likely to experience problems at a curve) was greater than that of a typical static horizontal curve warning sign (*16*).

A study of DCWSs similar to those used in this research project was also completed in the United Kingdom (*33*). The DCWSs were smaller than those used in this research study and they were installed along two-lane roadways. Vehicle speed data were collected seven days before

the installation and one month and one year after the installation (*33*). A reduction in mean vehicle speed of about 2 to 7 mph was found and it appears that the lower vehicle speeds were sustained when data was collected in the long term (*33*). Similar reductions of 3 mph in mean and 85th percentile vehicle speeds were also found in South Carolina for another type of DCWS (*34*). No studies, however, were found that specifically indicated they were completed along low-volume, local rural roadways.

Finally, the FHWA "Desktop Reference for Crash Reduction Factors" document that was noted previously also included crash reduction factors for "Dynamic/Variable Speed Warning Signs" (*23*). In this document, however, these crash reduction factors are referenced to a currently unpublished report related to the recently published Highway Safety Manual (*23*). The report that was referenced apparently indicates that the installation of these types of signs can be expected to reduce all crashes by 46 percent and injury crashes by 41 percent (*23*). It should be noted, however, that the standard errors declared for these meta-analysis crash reduction summary results are 17 and 62 percent, respectively (*23*). As previously noted, however, there is also a website now that provides rankings for the robustness of the crash reduction or modification factors (www.cmfclearinghouse.org) and the Highway Safety Manual has now been published (*25*). These two resources are now critical for the evaluation of safety impacts related to roadway improvements (*25*).

Summary of Findings

The general findings of several research projects that focused on the relationship between horizontal curve geometrics, speed, and safety are described in this chapter. The vehicle speed impacts of horizontal curve geometrics along two-lane roadways (the focus of this project) have been studied quite extensively. Some of the more critical horizontal curve characteristics that appear to impact vehicle speed are radius, superelevation, and approach tangent vehicle speed. The IHSDM software "flags" horizontal curves if the change in predicted vehicle speed at that location is too high. The difference in the approach speed and the vehicle speed needed to properly negotiate a horizontal curve is an important indicator of its potential level of safety. Studies that attempt to define the relationship between horizontal curve geometrics and vehicle crashes produce results similar to those that focus on vehicle speed. In general, the number of crashes on a horizontal curve appears to be related to its length and radius. In addition, the existence of a spiral horizontal curve design also appears to have an influence. The chapter concludes with a summary of the research about the potential impacts traditional warning signs and dynamic warning signs. Overall, there does appear to be a reduction in vehicle crashes when traditional horizontal curve warning signs are installed. In addition, several studies have considered the speed impacts of different dynamic warning sign installations. The studies that appeared to be most relevant to this project showed vehicle speed reductions attributed to the dynamic signs of zero to 7 mph. Crashes also were reduced in several studies of various dynamic warning sign systems. No studies were found, however, that specially indicated that they were completed for study sites along low-volume local rural roadways.

Chapter 3. Study Site Selection Methodology and Results

This chapter describes the selection of the three study sites used in this research project. More specifically, the site selection process is summarized and the databases are identified from which the candidate horizontal curves were selected. Then, the required and desirable characteristics used to define the viable project study site locations are described. The results of some preliminary vehicle speed data collection that was completed at four to six locations in each county to assist with the final site selection are also discussed. Finally, the study sites used in this research project are identified.

Horizontal Curve Study Site Selection Methodology

The objective of the study site selection methodology used in this research project to identify horizontal curve approaches in each of the participating counties (i.e., Meeker and McLeod County) that had vehicle speed and other potential safety-related characteristics that might be improved through the installation of a DCWS. In Meeker County this process started with the consideration of horizontal curves that had already been proactively prioritized (e.g., high, medium, and low) for a potential safety improvement (*35*). A series of factors were used to prioritize the horizontal curves in Meeker County and this list was being used to assist with the safety-related decision-making process. A similar activity was funded and completed as part of this project for McLeod County and a brief draft report with the results are in Appendix A. The results from these countywide horizontal curve prioritizations were used to create a list of candidate study sites in each county. The characteristics of these candidate study sites were then evaluated and four to six horizontal curve approaches in each county that were considered physically viable for this project were selected. The horizontal curve approach characteristics used to select these viable study sites are described in this chapter. The four to six physically viable study sites in each county were then considered more closely through the collection and summary of visually identified point of curvature (PC) vehicle speeds. The DCWS evaluated during this project were installed at this location. Ultimately, three study sites were selected as DCWS installation locations.

It should be noted that at the beginning of this research project three counties in Minnesota had agreed to participate. Unfortunately, one of these counties, due to unforeseen circumstances, could not continue. The activities/tasks completed as part of the study site selection process were completed for three counties, but only the results from the two counties (Meeker and McLeod County) are summarized in this report.

Candidate Study Site Databases

As noted above, the two counties that participated in this project have a large number of horizontal curves. A large portion of these horizontal curves were proactively prioritized to assist the counties with their safety improvement decision-making. The horizontal curves that were prioritized were used in this project as the candidate study site list in each county. The focus for this project, however, was on those horizontal curves assigned a high or medium priority. The processes used to complete the prioritization in each county are described below.

McLeod County Horizontal Curve Safety Improvement Prioritization Process

Horizontal curves in McLeod County were proactively prioritized as part of this research project. The prioritization process used was that applied in Freeborn County, Minnesota and documented in the *Freeborn County Road Safety Audit* (*36*). Freeborn County was actually the first county in Minnesota to complete this prioritization process. The priorities assigned to the horizontal curves in McLeod County were defined in the following manner:

- High Priority
  - Horizontal curve had a visual trap on or both approaches, or
  - Horizontal curve radius was equal to or less than 800 feet and had at least one crash (during the five years considered, 2003 to 2007), or
  - Horizontal curve was located along a roadway corridor where other horizontal curves already had additional delineation installed (e.g., chevrons).
- Medium Priority
  - Horizontal curve has a radius of equal to or less than 800 feet, or
  - Horizontal curve had at least one crash (during the five years considered, 2003 to 2007)
- Low Priority
  - Horizontal curves with a radius greater than 800 feet, no crashes (during the five years considered, 2003 to 2007), and no visual trap on one or both approaches.

Overall, a total of 242 horizontal curves were prioritized in McLeod County (using the approach described above). Horizontal curve radii were estimated from aerial photos and crash data from 2003 to 2007 were summarized. Sixty (approximately 25 percent) of the horizontal curves evaluated were assigned a high priority and 78 of the horizontal curves (approximately 32 percent) were assigned a medium priority. These two groups of horizontal curves were considered the McLeod County candidate study site database. The remainder or the horizontal curves were either given a low priority or it was noted that they already had been delineated by chevrons (and a priority was not assigned).

Four horizontal curve characteristics were considered in the McLeod County prioritization. These characteristics were selected used in the prioritization process were used because they were considered indicators of the overall existing or potential safety at a particular horizontal curve. First, the existence of a visual trap on the approaches to a horizontal curve was noted. A visual trap occurs when the roadway does not visually appear to bend (e.g., a row of trees or telephone poles continues straight, but the roadway bends) from the viewpoint of the driver. An example of this is shown in Figure 3.1. This situation may result in a driver misinterpreting the need to reduce speed and/or change direction along a roadway alignment. Second, the radius of the horizontal curve was estimated (using Google Earth™) as either longer or shorter than 800 feet. The selection of an 800 foot horizontal curve radius as a safety indicator was primarily based on the results of horizontal curve research from Texas (See Figure 3.2) and a summary of crash rates for various horizontal curve radii within two Minnesota Department of Transportation (MnDOT) Districts (See Figures 3.2 and 3.3) (*36*). These graphs appear to show a dramatic increase in overall crash rates and/or severe injury/fatal crash rates at horizontal curves when the radius is 800 to 1,000 feet (*36*). Third, because of the low volumes that generally exist along county roadways it was also decided that the occurrence of any type of crash (regardless of severity) at or near a horizontal curve for a time span of five years should also be considered an

indicator of the safety at a site. In addition, if an unimproved horizontal curve occurred along a roadway where other horizontal curves had already been delineated (e.g., chevrons had been added) it was determined that it should also probably be improved and assigned a higher priority.

Figure 3.1: Example of Visual Trap

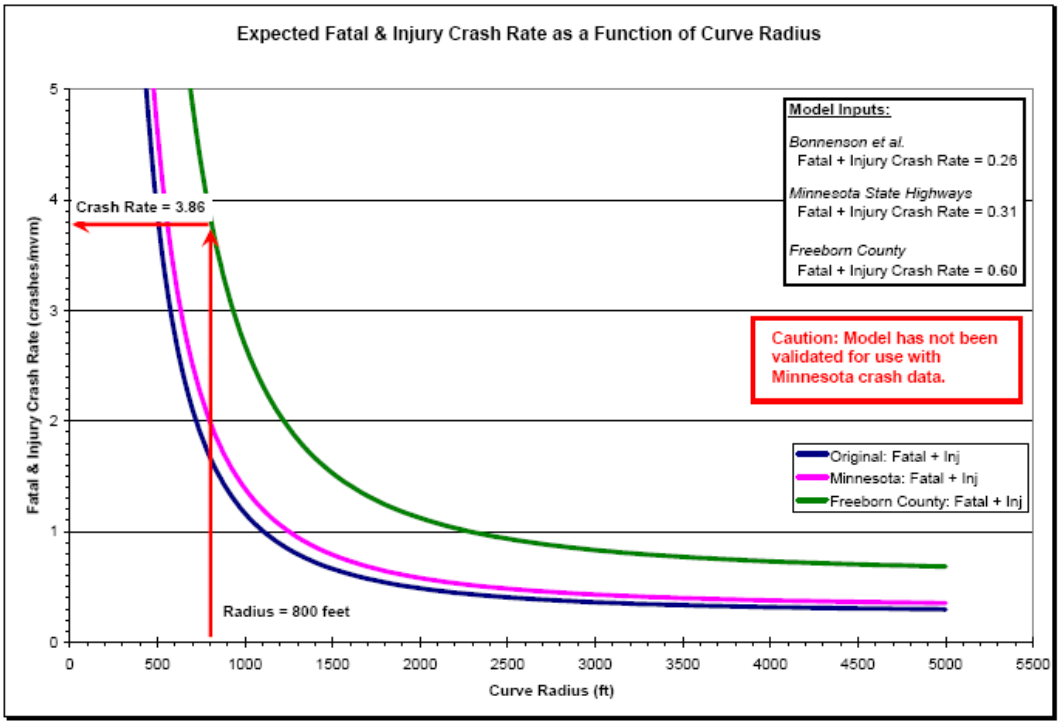

Figure 3.2: Texas, Minnesota, and Freeborn County Curve Radius and Crash Results (*36*)

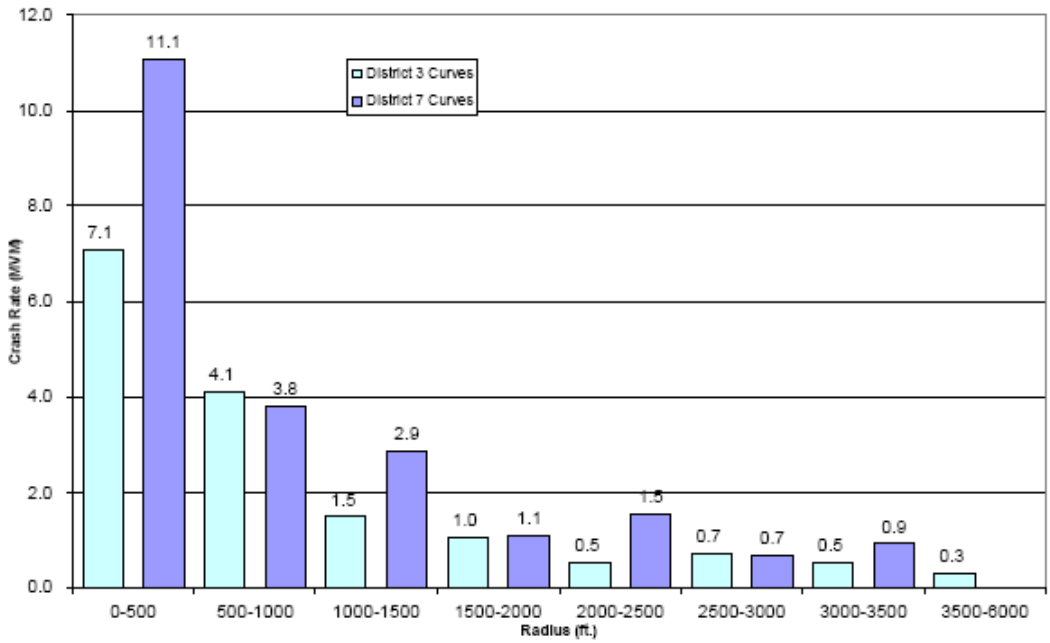

Figure 3.3: Minnesota DOT District 3 and 7 Curve Radius and Crash Rate Results (See Appendix A)

It is important to note that this prioritization (and that done in Meeker County also) was completed for individual horizontal curves. However, in some cases approach warning signs can apply to more than one horizontal curve. An example of this situation is the reverse horizontal curve (See Figure 3.1) or turn warning sign. A "winding road" warning signs can also refer to any number of individual horizontal curves. For this research only those horizontal curve approaches with a warning sign were considered, and they were identified in the candidate study site database during the site visits.

Meeker County Horizontal Curve Safety Improvement Prioritization Process

The Meeker County horizontal curve prioritization was not done as part of this project, but its results were used. Several years ago Meeker County had 167 of its horizontal curves proactively prioritized for safety improvement decision-making purposes. Each of these horizontal curves were prioritized as high, medium, or low, and the results of this prioritization can be found in the *Meeker County Road Safety Audit Review* (*35*). The definitions of high, medium, and low priority horizontal curves in in Meeker County were slightly different than that in McLeod County (see previous description), but the characteristics considered were the same. In Meeker County the prioritization different levels of prioritization were defined in the following manner:

High Priority

- Horizontal curve had a visual trap on one or both approaches, or
- Horizontal curve radius was equal to or less than 800 feet, or
- Horizontal curve had at least one crash (during the five years considered, 2002 to 2006), or
- Horizontal curve was located along a roadway corridor where other horizontal curves already had or needed additional delineation installed (e.g., chevrons).

- Medium Priority
  - Horizontal curve had no crashes (during the five years considered, 2002 to 2006), but was along a roadway corridor where other horizontal curves already had or needed additional delineation installed (e.g., chevrons).
- Low Priority
  - Horizontal curves with a radius greater than 800 feet, no crashes (during the five years considered, 2002 to 2006), and no visual trap on one or both approaches.

As previously noted, a total of 167 curves were prioritized in Meeker County (using the approach described above). Curve radii were estimated from aerial photos and crash data from 2002 to 2006 were summarized. Fifty-two (approximately 31 percent) of the horizontal curves were assigned a high priority and 19 of the horizontal curves (approximately 11 percent) were medium priority. These two groups of horizontal curves were considered the Meeker County study site database. The remainder or the curves were either given a low priority or it was noted that they already had been delineated by chevrons (and a priority was not assigned by the authors of the report).

Overall, the four horizontal curve characteristics used in the Meeker County prioritization are the same as those used in McLeod County. However, these characteristics are applied in a slightly different manner within the prioritization process. One of the more important differences in the Meeker County prioritization is that a crash *or* a horizontal curve radius less than or equal to 800 feet will result in a "high" priority designation. In the previously described McLeod County prioritization this designation required both (i.e., "*and*") of these horizontal curve characteristics. In other words, the medium priority definition in McLeod County was essentially that used to define a horizontal curve as high priority in Meeker County. In addition, a medium priority horizontal curve designation in Meeker County also included those locations that have no crashes but are near other curves that *need* or had been improved with additional delineation. In McLeod County only those horizontal curves that were near other curves that had already been improved were included in this type of comparison.

The process used to define the safety improvement prioritization of horizontal curves in the counties was changed in an attempt to improve the output. Preferably, the methods of prioritization used in Meeker and McLeod County would have been the same for this research project. The differences in the Meeker and McLeod County prioritization processes, however, were small. In addition, it is more important to this project that the horizontal curves being considered are those produced by the prioritization process used in each of the participating counties to assist with safety improvement decisions. Even more important, the differences in the Meeker and McLeod County prioritization processes only impacted whether a horizontal curve was assigned a high or medium priority. The definition of the horizontal curves with a low

priority was the same in each county. This research project considered horizontal curves assigned with a medium or high priority as part of its candidate study site database. The database in each county, therefore, would be the same for the two proactive prioritization processes described in this report.

Viable Study Site Horizontal Curve Characteristics

The next step in the study site selection process included the identification of four to six physically viable study site locations in each county from the candidate study site database defined by the proactive prioritization process. The candidate study site data for each county were those identified with a "high" or "medium" priority for a safety improvement. The national DSFS demonstration study project team, however, also proposed a series of required and desirable characteristics for a horizontal curve approach to be a viable for a DCWS evaluation. This research project used a review of the physical characteristics in the following list to define four to six physically viable study sites. The list is a combination of what was used in the national DSFS demonstration study (or a slight variation of what was used) and additional characteristics that were considered more appropriate for viable low-volume roadway study sites. The characteristics used in this research to identify viable study sites including the following:

- Required Characteristics for Viability
  - Two-lane roadway
  - Rural environment (e.g., approximately one mile or more from an urban area or significant development)
  - No geometric design changes (not including resurfacing) three years before or after installation of the DCWS
  - Posted speed limit of 50 mph or more on the approach
  - Point of curvature (PC) vehicle speed data that meets the national DSFS demonstration study definition of a location with potential speed concerns (This is a characteristic that was added as a requirement for this research project due to the low-volume nature of the roadways considered. The definition of a location with potential speed concerns and the results of the PC data collection are described later in this report.)
  - Existing warning sign on approaches to individual or, if appropriate, group of horizontal curves (e.g., reverse curve)

- Desirable Characteristics for Viability
  - Crashes in the proximity of the horizontal curve that might be the result of vehicle speed and/or inattention (five years of crash data were considered in the prioritization processes used to develop the candidate study site database)
  - Project defined vehicle speed data collection locations (e.g., visually identified PC, "within curve", and control) free of significant intersections and driveways
  - Average daily traffic (ADT) volumes of at least 100 vehicles per day (vpd)
  - Tangent length on horizontal curve approach that is long enough to allow full approach speed to be attained
  - Existed advisory speed limit sign posted
  - County engineer and/or local agency concerns

Overall, a horizontal curve approach had to be on a two-lane high-speed (i.e., posted speed limit of 50 mph) roadway with no recently completed or planned construction and generally surrounded by rural land uses (i.e., more than one mile from an urban area or significant development) to be considered a viable study site for this research project. Other physical characteristics of the horizontal curve approach also needed to be appropriate for this project. For example, the location of driveways and intersections needed to allow the proposed data collection at the horizontal curve visually identified PC, "within" the curve, and at a control point. A significant driveway or intersection (with or without turn lanes) at these locations could not occur. Viable study sites also needed to have a traditional warning sign. The DCWS installed as part of this project was intended to supplement an existing sign.
Finally, the vehicle speed at the visually identified PC of a horizontal curve that met all the physical characteristics of a viable study site also needed to meet the national DSFS demonstration study definition of a location with potential vehicle speed concerns. The definition of a location with potential vehicle speed concerns is described in the next section of this report.

The physical characteristics listed and described above were collected for all the high and medium priority horizontal curves in the McLeod and Meeker County candidate databases. These data were collected with digital photos, roadway measurements, and documentation of existing conditions that was done during the field visits. The countywide proactive horizontal curve safety improvement prioritization reports also contained some of the other characteristics (e.g., the number and severity of crashes at or near the horizontal curve). This information was used to identify four to six horizontal curve approaches per county that were physically viable for this project. Then, vehicle speeds were collected at the visually identified PC of these horizontal curves to determine if they met the national DSFS demonstration study definition of a location with potential vehicle speed concerns. The results of this data collection are described later in this chapter.

Locations with Potential Vehicle Speed Concerns

The national DSFS demonstration study project team considered vehicle speed at the PC of a horizontal curve as one factor in their study site selection. They concluded that a mean or 85th percentile vehicle speed at or greater than 5 mph or more above the posted speed or advisory speed limit (if it existed) at the visually identified PC of a horizontal curve defined a location with a potential vehicle speed concern. This project also used this definition of a "location with potential vehicle speed concern" as a critical factor in the selection of its study sites. Therefore, vehicle speeds were collected at the visually identified PC of four to six horizontal curve approaches in Meeker and McLeod County. The results of this activity and a review of the horizontal curve physical characteristics were used to select the final study sites.

Candidate Study Site Vehicle Speed Viability

The physical characteristics of the horizontal curves in the candidate study site database were compared to the required and desirable lists of characteristics of viable study sites. This comparison was used to identify four to six potentially viable study sites in each county. Vehicle speeds at the visually identified PC of each potential study site (i.e., horizontal curve approach) were then collected. The results of these data collection efforts were considered a critical factor in the identification of the final three study sites. Initially, it was proposed that this preliminary

vehicle speed data collection could be completed with a radar gun, but the low ADTs at the potential study sites did not make this a reasonable approach. Therefore, automatic pneumatic tube traffic data collection devices were placed at the visually identified PC of four to six potentially viable horizontal curve approaches in each county. These data collection devices remained at each potential study site for three to five days.

Four to six potentially viable horizontal curve approaches in each county are identified in Tables 3.1 and 3.2. Their locations are shown graphically in Appendices B and C. The visually identified PC vehicle speed collected at each potential study site also summarized in Tables 3.1 and 3.2. These tables include both the mean and 85th percentile speeds calculated at each location. In addition, the tables also provide the highway and curve designation of the potential study sites, the travel direction of primary interest, the posted advisory speed limit (if any), the database size (i.e., the number of vehicle speeds used in the calculations) and the visual trap and crash information collected as part of the prioritization process.

Tables 3.1 and 3.2 also include footnotes that explain the data used to calculate the mean and 85th percentile vehicle speeds at each potential study site. In general, only those vehicle speeds that could be classified were used in these calculations, and it was also concluded that any vehicle the recorders indicated was traveling at 100 mph or more was not likely to be valid (there were only 2 of these at 10 sites considered, however). Vehicle speed data from three hours after the pneumatic tubes were set and three hours before they were removed were also not considered. The deletion of data was a cautionary approach to eliminate the possible influence of the data collection team in the field near the study site. Finally, it should also be noted that the calculations include all valid vehicle speeds. Therefore the vehicle speed statistics are not "free-flow" statistics. Due to the low ADT along the roadways considered, however, almost all the vehicle speeds collected are likely to be at or near "free-flow". In fact, a comparison of "free-flow" and "non-free-flow" mean and 85th percentile vehicle speeds (using a five second gap between vehicles to define "free-flow") calculated from a sample of speeds at the potential study site with the highest estimated ADT (i.e., 3,900 vehicles per day) revealed a difference of less than one mph. In addition, the differences in the "free-flow" and "non-free-flow" vehicle speed statistics at the other potential study sites, which have much lower ADTS, are expected to be much smaller. The general assumption is also that the proportion of "free-flow" and "non-free-flow" vehicles will also stay approximately the same from one data collection time period to another and would not have an impact on the analysis of any changes in vehicle speed.

Meeker County Horizontal Curve Study Site Vehicle Speed Viability Results

In August 2009 vehicle speed data were collected at or near the visually identified PC of six horizontal curve approaches within Meeker County. The locations of the six horizontal curves are shown in Appendix B. The horizontal curve approach of interest, the number of vehicle speeds used in the calculations, and the posted advisory speed limit (if any) are shown in Table 3.1. In addition, the mean and 85th percentile vehicle speeds calculated for each data collection location and the visual trap and number/type of crashes recorded (from 2002 to 2006) at or near the horizontal curve are indicated. The visual trap information and number/type of crashes were acquired from the results of the countywide proactive safety improvement prioritization process (described previously) and verified by site visits and a review of the crash data. The posted or implied (i.e., driver assumed) speed limit on all the horizontal curve approaches was 55 mph.

Table 3.1: Meeker County Site Selection Vehicle Speed Summary1

Highway	Curve Designation	Inbound Approach Direction	Number of Vehicle Speeds	Posted Advisory Speed Limit (mph)	Mean Vehicle Speed (mph)	85th Percentile Vehicle Speed (mph)	Crash and Visual Trap Information[2]
CSAH 1	01-09	SB	1,622	None	55	60	1K, 1PDO, & Visual Trap
CSAH 2	02-04	NB	792	None	56	61	Visual Trap
CSAH 3	03-02	EB	401	40	51	57	1B
CSAH 3	03-03	WB	448	40	53	60	1C
CSAH 19	19-03	SB	444	None	48	56	1A
CSAH 25	25-01	SB	350	None	54	60	1K, 2A, & 2B

[1]Mean and percentile speed calculations based on all vehicle speeds less than 100 mph.
[2]Crash data from 2002 to 2006. K = fatality, PDO = property damage only, A, B, C = levels of injury crash. Crash data and visual trap information updated as needed from a re-review of the crash data and site visits. Not all the information above will match the *Meeker County Road Safety Audit Review* report (*35*).

The volume and vehicle speed characteristics of the six horizontal curve approaches considered in Meeker County (See Table 3.1) were all somewhat different. For example, the number of vehicle speeds collected in the critical inbound direction of traffic flow ranged from 350 to 1,622. In addition, only two of the horizontal curves considered had a posted advisory speed limit. These two approaches were along CSAH 3. The mean vehicle speeds calculated for the visually identified PC of each horizontal curve approach ranged from 48 to 56 mph. More specifically, the mean vehicle speeds at the visually identified PC of the CSAH 3 horizontal curves were 11 and 13 mph greater than their 40 mph posted advisory speed limit. At the visually identified PC of the horizontal curves with no posted advisory speed limits, however, the mean vehicle speeds ranged from seven mph below to one mph above the driver assumed 55 mph approach speed limit. The 85th percentile vehicle speeds at these horizontal curve visually identified PCs ranged from 56 to 61 mph (i.e., one to six mph above the driver assumed 55 mph approach speed limit). At the CSAH 3 horizontal curve visually identified PCs the 85th percentile speeds were also 17 and 20 mph greater than the 40 mph posted advisory speed.

All of the horizontal curves listed in Table 3.1 were identified as a high priority in the Meeker County proactive safety improvement prioritization plan. In one case, there was a visual trap and no crashes, but in another case there five injury or fatal crashes recorded at or near the horizontal curve. These crashes were only one factor considered in the proactive safety improvement prioritization. In addition, not all of the crashes at a horizontal curve are likely to be influenced by the potential speed reduction impact of a DCWS. The visual traps identified could also be applicable to one or both approaches of the horizontal curve. These details were considered more closely before the final selection of the study sites.

McLeod County Horizontal Curve Study Site Vehicle Speed Viability Results

In August/September 2009 vehicle speed data were collected at or near the visually identified PC of four horizontal curve approaches within McLeod County. These data were collected for a

time span of three to five days at each potential study site. The locations of the four horizontal curves are shown in Appendix C. Table 3.2 includes the designation of the horizontal curve approach of interest, the number of vehicle speeds used in the calculations, and the posted advisory speed limit on the horizontal curve approach (if any). The mean and 85th percentile vehicle speeds calculated for each data collection location and the visual trap and number/type of crashes recorded (from 2003 to 2007) at or near the horizontal curve are also indicated. The visual trap information and number/type of crashes are from the results of the the countywide proactive safety improvement prioritization process (described previously) and verified by site visits and a review of the crash data. The posted or implied speed limit on all the horizontal curve approaches was 55 mph.

Table 3.2: McLeod County Site Selection Vehicle Speed Summary[1]

Highway	Curve Designation	Inbound Direction	Number of Vehicle Speeds	Posted Advisory Speed Limit (mph)	Mean Vehicle Speed (mph)	85th Percentile Vehicle Speed (mph)	Crashes and Visual Trap Information[2]
CSAH 7	07-06	NB	1,005	50	57	63	2PDOs & Visual Trap
CSAH 7	07-20	NB	523	35	47	52	1PDO, 1C, & Visual Trap
CSAH 8	08-07/08	EB	6,926	None	56	60	4PDOs & 1C
CSAH 9	09-07	SB	1,159	None	56	60	1A & Visual Trap

[1]Mean and percentile speed calculations based on all vehicle speeds less than 100 mph.
[2]Crash data from 2003 to 2007. K = fatality, PDO = property damage only, A, B, C = levels of injury crash. Crash data and visual trap information updated as needed from a re-review of the crash data and site visits. Curve designation 08-07/08 is signed as a reverse curve and the crash/visual trap information provided is for both individual curves.

Once again, the volume and vehicle speed characteristics of the four horizontal curve approaches considered were all somewhat different. The number of vehicle speeds collected in the critical inbound direction of traffic flow, for example, ranged from 523 to 6,926. In addition, only two of the horizontal curves considered had posted advisory speed limits. One of the horizontal curves was posted at 35 mph and the other at 50 mph. The other two data collection sites (a horizontal curve and a reverse curve (i.e., CSAH 8)) had no posted advisory speed limits. The mean vehicle speeds calculated at the visually identified PC of each horizontal curve ranged from 47 to 57 mph. This measure was 7 and 12 mph greater than the posted advisory speed limit at the two horizontal curves that had them and was one mph greater than the posted or implied speed limit at the two curves that did not. The 85th percentile vehicle speeds at the visually identified PC of the four horizontal curves ranged from 52 to 63 mph. These speeds were 13 and 17 mph greater than the posted advisory speed limits at the two CSAH 7 horizontal curves. At the two horizontal curves with no posted advisory speed limit, however, the 85th percentile vehicle speed was only five mph greater than the 55 mph posted or implied speed limit.

All the horizontal curves considered, except the CSAH 8 reverse curve, were identified as a high priority in the McLeod County proactive safety improvement prioritization. The two horizontal curves that define the CSAH 8 reverse curve, on the other hand, were prioritized as low and medium (but it was assumed to be a medium priority facility during this research project). Three of the horizontal curves considered in McLeod County had visual traps (but this was only for the southbound direction of Curve 7-20) and these locations had either one "A" injury crash, 2 PDO crashes, or PDO and "C" injury crashes. The CSAH 8 reverse curve, on the other hand, experienced 4 PDO crashes and one "C" injury crash. These crashes were only one factor considered in the proactive safety improvement prioritization process. In addition, not all of the crashes noted in Table 3.2 would likely be impacted by the potential speed reduction impacts of a DCWS. The visual traps identified could also be applicable to one or both approaches of the horizontal curve. These details were considered before the final selection of the study sites. It was also learned, for example, that chevrons had been implemented at Curve 09-07 (See Table 3.2) in 2006.

Study Site Selection Results

A review of the candidate study sites and the vehicle speed data collection results described in the last section of this report were used to select a total of three horizontal curve approach locations in Meeker and McLeod County. The comparisons made and characteristics considered, along with the results of the selection process, are described below

Meeker County Study Sites Selected

Many candidate horizontal curves were considered in Meeker County. A large number of them met some of the required characteristics defined for this research project and even more met some of the desirable characteristics. Six potentially viable horizontal curve approaches were selected as finalists based on a review of their attributes. Vehicle speeds were then collected at the visually identified PC of these six locations. These data were collected to determine if they were locations with a speeding concern (as defined by the ongoing national DSFS demonstration study). All but one horizontal curve approach (the CSAH 19 site) considered in Meeker County (See Table 3.1) met this definition. Two study sites were selected for use in this research project. First, the southbound approach to Curve 25-01 along CSAH 25 (See Table 3.1) was selected. This segment of CSAH 25 has an estimated weighted ADT of approximately 630 vpd and the horizontal curve of interest has an estimated radius of 1,150 feet. The horizontal curve has no posted advisory speed limit and the posted tangent approach speed is 55 mph. The southbound mean and 85th percentile vehicle speeds at its visually identified PC are 54 and 60 mph (one mph less and five mph more than the posted speed limit). This horizontal curve, however, has also experienced five crashes in five years (See Table 3.1). The primary factors used in the selection of this particular horizontal curve were the preliminary vehicle speed results and crash data.

The second study site selected in Meeker County was the eastbound approach to Curve 03-02 along CSAH 3 (See Table 3.1) was selected. This study site is actually one end of a "broken back" curve in which two horizontal curves are separated by a short tangent section, but the facility is signed as one horizontal curve. This research project focused on the eastbound approach to this facility. The posted advisory speed for this horizontal curve is 40 mph, and the

estimated ADT is approximately 455 vpd. The horizontal curve of interest has an estimated radius of 1,200 feet, and while the approach speed on the approach tangent is not posted, drivers assume it is 55 mph. This assumption is supported by the fact that the eastbound mean and 85th percentile vehicle speeds at or near the visually identified PC of Curve 03-02 were 51 and 57 mph (which is also 11 and 17 mph more than the posted advisory speed limit) (See Table 3.1). Only one "B" injury crash was recorded between 2002 and 2007 at or near this horizontal curve facility (See Table 3.1). This horizontal curve, therefore, was selected primarily based on the results of the preliminary speed data collection (i.e., its vehicle speeds were much higher than the posted advisory). This horizontal curve is also somewhat "hidden" to eastbound drivers. These drivers see the horizontal curve warning sign before the actual horizontal curve. These types of "hidden" horizontal curve approaches are good locations for DCWSs.

McLeod County Study Site Selected

A large number of horizontal curves were also considered as candidate study sites in McLeod County. Many of the approaches to these horizontal curves met most of the required and desirable characteristics needed for them to be useful to this project. Four potentially viable horizontal curve approaches were selected as finalists based on a review of their attributes. Vehicle speeds were then collected at the visually identified PC of these four locations. These data were collected to determine if they were locations with a speeding concern (as defined by the ongoing national DSFS demonstration study). All the horizontal curve approaches considered (See Table 3.2) met this definition. The McLeod County site selected for the implementation of a DCWS, however, was the northbound approach to Curve 06 along CSAH 7 (See Table 3.3). This segment of CSAH 7 has an estimated weighted ADT of approximately 710 vpd (which is much higher than the two Meeker County study sites), and the horizontal curve has an estimated radii of 850 feet. The posted speed limit on the tangent approach is 55 mph and the horizontal curve has a posted advisory speed of 50 mph. The northbound mean and 85th percentile vehicle speeds at its visually identified PC are 57 and 63 mph, respectively (i.e., 7 and 13 mph more than the posted advisory speed limit). In addition, this horizontal curve has experienced two property damage only crashes in five years, and also has a visual trap. The vehicle speed data collection results, crash data, and the physical characteristics of this horizontal curve were used as the primary factors in the selection of this study site.

Summary of Findings

This chapter described the overall methodology used to select the study sites for this research project. First, the origin and factors used to create a candidate database in each county were described. These databases were the result of proactive horizontal curve safety improvement prioritization processes that was completed in both Meeker and McLeod Counties. The Meeker County prioritization was completed years ago, but the McLeod County prioritization was part of this research project. A large number of horizontal curves in each county were prioritized as high, medium, and low for proactive safety improvements. The candidate study sites for this research project were those assigned a high or medium priority. The methods and factors used to complete these prioritizations are described in this chapter. Crash data was only one factor considered. Two other factors included the radii of the horizontal curve and the existence of the visual trap.

This chapter also listed and described the required and desirable characteristics a horizontal curve would need to have in order to be considered a viable study site for this research project. The documentation of the countywide proactive horizontal curve safety improvement prioritization process and site visit results helped define many of these characteristics at each candidate study site. Four to six potentially viable horizontal curve approach study sites were selected as finalists from this information and vehicle speeds at their visually identified PC were collected. A required vehicle speed characteristic for a study site to be viable was that the mean or 85th percentile vehicle speeds at the visually identified PC meet the definition of a "location with potential speed concerns" used by the ongoing national DSFS demonstration study. The results of the vehicle speed data collection effort and a consideration of the candidate study site characteristics were used to select the following horizontal curve approaches as study sites for this research project:

- Meeker County – Southbound approach of Curve 25-01 (See Table 3.1 and Appendix B) on CSAH 25
- Meeker County – Eastbound approach of Curve 03-02 (See Table 3.1 and Appendix B) on CSAH 3
- McLeod County – Northbound approach to Curve 07-06 (See Table 3.2 and Figure C) on CSAH 7

The three locations listed above are the horizontal curve approaches at which a DCWS was implemented during this research project. The selection and installation of the DCWS, including the challenges encountered, are described in the next chapter.

Chapter 4. Sign Selection and Pre-/Post-Installation Challenges

Three horizontal curve study site approaches were selected for the installation sites of a DCWS. Two of these study sites were in Meeker County, Minnesota and one study site was in McLeod County, Minnesota. All three study sites are on low-volume, rural local roadways that have been proactively identified as a high priority for safety improvement. They also have vehicle speeds at their visually identified PC that are higher than desired. This chapter describes the comparison and selection process this research project team believes the ongoing national DSFS demonstration study used to select one or more dynamic signs for evaluation. For consistency, the results of this process were also used in this research. It was important that this project evaluate one of the two signs ultimately selected by the national DSFS demonstration study team. The DCWS selected for evaluation in this project is identified in this chapter. In addition, the challenges experienced and overcome by the research project team and our local partners during and after the installation of the DCWS are described. The responses to these challenges are also noted.

Sign Selection Process and Factors

An objective of this research project was to follow, as much as possible, the guidelines and strategies used by the ongoing national DSFS demonstration study. This approach was selected by this project team to produce data and results that were as comparable to, or possibly combinable with, those from the national DSFS demonstration study. The DCWS used in this Minnesota research study, therefore, had be the same as one of those selected by the national DSFS demonstration study team. Fortunately, the sign comparison and selection process was already completed by the national DSFS demonstration study team when a DCWS needed to be selected for this research project. The national DSFS demonstration study team compared the characteristics of five dynamic signs to a set of required and desirable sign criteria. It is believed that the required DCWS criteria included the following:

- Mounting is permanent on a standard wood or metal pole
- Ability to display a warning and/or a simple message (e.g., XX mph, “TOO FAST”, “SLOW DOWN”, etc.) to drivers exceeding a particular speed
- Durable during the period of study and for different weather situations
- Self-contained power (e.g., AC or solar)
- Mountable on standard wood or metal pole
- Cost of less than $10,000 (installed, with support and maintenance)
- Meet all applicable Manual on Uniform Traffic Control Devices (MUTCD) requirements or the ability to be approved for MUTCD experimental study requirements
- Provide repeatable and accurate speed measurements
- Project a clear, bright, non-glare, easily readable message to motorists

There were also several desirable criteria or factors considered during the sign selection process by the national DSFS demonstration study team. These desirable criteria included the following:

- Acceptable sign performance (based on references)
- Sufficient quantity of signs deployed to determine sign performance

- Ability to store and transmit data
- Reasonable installation and mounting requirements for proper operation and viewing
- Programmable display by calendar or remote input
- Ease of maintenance

An evaluation and comparison criteria matrix for the signs considered in the evaluation was developed by the national DSFS demonstration study team that summarized how well each one met the required and desired criteria. The matrix also included other useful information. More specifically, it contained the following information about each sign that was compared:

- Basic estimated sign cost (without pole, installation, or maintenance)
- Estimated sign cost with the addition of $3,000 for pole, installation, and maintenance
- Does the sign meet applicable MUTCD requirements or can it be approved as a MUTCD experiment?
- Does the sign allow permanent mounting with standard wood or metal support?
- Can the sign display a simple message based on speed threshold?
- Is the sign durable enough to survive study period and various climates?
- Options for power to sign
- Sign style: Does the sign have a simultaneous display of hazard and/or action to take (but is otherwise blank)
- How does the sign appear to the driver?
- Description of sign operation
- Text and symbol dimensions (Note: The dimensions included for the sign ultimately used in Minnesota were smaller than what was applied here.)
- Does the sign meet the minimum criteria of the research project?
- Other factors described in the sign matrix :
  - Sign warranty
  - Data storage capacity
  - Method of downloading data
  - Method to program sign operation
  - Ability to program display by calendar
  - Automatic nighttime dimming option
  - Acceptable signing performance from references
  - Approximate number of signs deployed worldwide

Sign Selection Results

Information was gathered by the national DSFS demonstration study team about the characteristics above for five dynamic signs. Overall, the national DSFS demonstration study team concluded that three of the five signs they compared met the primary sign selection criteria. They asked for bids on all three. All three estimates of sign installation costs were above the desirable $10,000 (however, two were within $700). The results in their decision matrix (and presumably the bid amounts) led to the selection and use of one curve display sign and one speed display sign. Based on these results and additional advice from the national DSFS demonstration study team members it was concluded the curve display sign was the most appropriate for this project. The DCWS is shown in Figure 4.1 along with an explanation of its operation. The threshold or activation vehicle speed used for this sign during this project and the national DSFS

demonstration study was the 50th percentile vehicle speed at the visually identified PC of the study site. For this study this vehicle speed was 55 mph at all three locations. Overall, the ability to properly evaluate two types of signs was not considered realistic with only three study sites. The DCWS selected for consideration appeared to be more appropriate for horizontal curves on low-volume, rural roadways.

Sign Display #1 - Blank

Measured vehicle speed is less than set speed threshold or no vehicle is present.

Sign Display #2 – Activated with "SLOW DOWN" and Top/Bottom Alternating Lights

Measured vehicle speed is equal to or greater than set speed threshold

Figure 4.1: Dynamic Curve Warning Sign Selected

Sign Installation Process

The DCWS selected for use in this research project (See Figure 4.1) was ordered in the summer of 2009. All three signs were delivered during the winter months of 2009/2010 and the county highway department staff began to prepare for their installation in the spring of 2010. There were several challenges to the installation of these signs, given the support system suggested (described below), for the county highway departments to overcome. In addition, post-installation challenges were also encountered. Both pre- and post-installation challenges and responses are described in the next section of this report. A summary of some sign installation field observations are also included.

Pre-Installation Challenges and Responses

The installation of the DCWSs used in this project was completed by the staff of the participating county highway departments. The counties agreed to assist with the installation during the proposal stage of this project. At that time, the type and size of the sign and the sign support structure to be suggested by Mn/DOT was unknown. The selection of the DCWS and the sign support structure introduced some challenges for the county highway departments before and after the installation was completed. Some of these challenges included:

- Small operating budgets
- Small workforce size
- Lack of experience with larger sign installation
- Equipment needs

Almost all of the challenges listed above are related to resources and are not unusual for small local highway departments in primarily rural areas. It should be expected that these types of challenges will also occur if the DCWS evaluated in this research was found to be effective and started to be installed within similar jurisdictions. In other words, these challenges will likely need to overcome during future installations. During this research project, the county highway departments overcame the first two factors for the four hour time period needed to install each DCWS. In addition, Mn/DOT provided guidance with respect to the installation of the sign support system. The counties also borrowed equipment to help with the installation when it was needed.

Sign Installation Summary and Field Observations

The team for this project consisted of researchers, Mn/DOT staff, and county highway department staff. The researchers and county highway department staff requested suggestions about what sign support structure to use with the DCWS selected from the Mn/DOT. Several sign installation support structures were considered by Mn/DOT and a square steel post system suggested for use. The system consisted of two 2.5-inch square steel tubes placed within a breakaway slip-base. It also included a 48-inch uni-base with a wing that was driven into the ground. Mn/DOT indicated to the research team that the vendor of this sign support structure suggested a two post design. Several Mn/DOT personnel (including the Mn/DOT Metro District Traffic Services Supervisor) and the Mn/DOT vendor for this sign support system were involved in the provided information to the county highway department. Overall, the DCWSs installed were approximately 74 inches in height and 46 inches wide (for a total area of about 23.64 square feet). The solar panel used also had an area of approximately 8.15 square feet (but it is angled in the field for sun exposure). The posts ordered from the vendor for these DCWS sign support installations were 20 feet in height and then cut to height in the field.

The DCWS (See Figure 4.1) were installed by county highway department staff at two study sites in Meeker County and one study site in McLeod County. The DCWS at each location in Meeker County were installed on May 19, 2010, but some preparatory sign base installation had already been completed the previous afternoon. The DCWS in McLeod County was installed May 20, 2010. The principal investigator (at that time) for this research project and a

representative of the sign vendor were also present during most of the installation process. Some observations by the principal investigator about the field installation are summarized below.

- The DCWS installation generally took 2 to 4 hours, but this time period depended on the equipment and personnel present.
- The height and weight of the DCWS, and its support structure, had not previously been used by either county.
- The characteristics of the installation appeared to require equipment that either would not normally be purchased by a county and/or were at the capability limits of typical county highway department sign installation equipment. Some of the actions taken to respond to this situation included:
  - A bucket truck was borrowed by one county (from another local jurisdiction) and made the installation of the DCWS and solar panel easier. An alternative was used by the other county and the sign panel was attached to the posts before they were placed in the base (this approach, however, required very careful placement due to the fragility of the solar panel).
  - The Minnesota DOT Metro District suggested the use of a 140 pound Rhino hammer for the base installation. Each of the counties had and used a smaller hammer and the amount of time to install the bases appeared to depend upon the soil type/characteristics and hammer size.
  - The use of a crane or boom was needed to place the sign posts in the support bases (for sign support structure suggested) was needed. In at least one case this installation approach, due to the sign/post height, seemed to be close to the capability limits (e.g., the crane or boom reach) of the equipment normally used by the county.
  - The appropriate height for the sign required the DCWS posts to be cut so that it was level. This process was done with a torch in one case and a saw in another.
  - The DCWS needed to be properly aimed. This aiming required that the sign support bases, when driven into the ground, be slightly offset from a right-angle with the roadway. Both counties built a "t-square" to "point" the sign at the correct location along the approaching roadway lane and achieve the proper base installation. This approach worked well in both cases.
- To repair or adjust something within the DCWS selected will require the use of a bucket truck, cherry picker, or a long ladder. The use of a ladder to complete this activity, however, will be difficult. Therefore, it is suggested that a ladder only be used for this activity if necessary and that two people be present if it is attempted. The signs are not installed on level ground (they are often in ditches, etc.) and the ladder must be held. First the ladder must be placed on one side of the sign to unlock the front face. Then the ladder needs to be shifted to the side of the sign (while someone holds the sign face open in some manner) so that work can be completed. The process then has to be reversed to close and lock the sign. Neither county appeared to own a bucket truck or something similar and this may limit the ability to maintain these type of signs.
- In one county the installation was completed with about 6 to 10 personnel. These personnel were used for traffic control and the operation of different pieces of equipment. Traffic control is especially important for the installation of DCWSs on roadways with no paved or gravel shoulder. The other county used what was assumed to be a typical sign installation crew of 2 personnel. This crew required some assistance in the installation of the DCWS but

could have accomplished it with more time. In general, it is suggested that a crew of 4 to 5 people for 2 to 4 hours may be a good estimate for the installation of these DCWSs in the field.

- All three DCWSs were aimed correctly during with the installation process. However, in two cases the radar system did not appear to be working properly (or possibly at the correct sensitivity level). The sign vendor was able to enter the sign and re-program them for additional sensitivity. This adjustment was accomplished in less than a half hour in both cases. It was subsequently learned that this was something that had occurred with other signs of this size in other rural locations. This issue should be corrected before similar installations are attempted. It was also suggested by several field personnel that the vendor may want to test the resiliency of the interior sign components to typical rural conditions (e.g., severe wind, vibrations, etc.). There were several concerns expressed about the robustness of the screws and/or bolts used.
- There was some discussion about the vibration and slight movement of the posts in windy conditions. Unfortunately, additional bracing for this type of sign support system has not been tested and the addition of another post on these signs did not appear to be physically possible or allowed. It is also unknown whether the addition of another post would have reduced or changed the vibrations and slight movements observed during windy conditions. It is suggested that the potential impact of this vibration and slight movement in the wind on the activation capabilities of the sign should be tested by the vendor.

Overall, the installation of the DCWS by the county highway department staff went well. Several challenges were overcome to produce this outcome and this was despite the fact that neither county had previously used the sign support system applied. All three signs were installed and operating within two days. The installation approaches used by the counties were similar, but involved different levels of resources. This variability allowed the observations and suggestions documented above to be made. The Meeker County installation process included more personnel and additional pieces of equipment (e.g., a bucket truck). McLeod County, on the other hand, provided a two person installation crew with what appeared to be their typical sign installation equipment (although a long ladder was also borrowed). The observations above, when combined with the pre-installation and post-installation challenges, should be taken into account if and when these DCWS are considered for use by other local jurisdictions (particularly those in rural areas). They will likely experience the same type of challenges.

Post-Installation Challenges and Responses

As noted above, the DCWSs for this project were initially installed on May 19, 2010 in Meeker County, Minnesota and on May 20, 2010 in McLeod County, Minnesota. Unfortunately, on March 23, 2011, during what was considered to be an unusual weather event (e.g., very high winds and very heavy snow sticking to the DCWS), the CSAH 25 DCWS fell down. It was observed that the bolts in the sign support structure were not sheared or broke and that it appeared as if the support had slipped out of its base. The addition of another sign post was considered, but the project team did believe this was allowed for the size of the DCWS. It was generally agreed that the unusual nature of the weather event and orientation of this DCWS (e.g., an open area and facing north) may have combined to cause this incident. The two other DCWSs installed for this project (one within approximately 10 miles of the CSAH 25 DCWS

and the other in an adjacent county) had remained in place and were checked. The DCWS solar panel at CSAH 25 was replaced and the structure was reinstalled on June 20, 2011. Unfortunately, a similar incident occurred later in this research project. In November 2011 the DCWS at the CSAH 7 study site in McLeod County also fell. Once again the bolts in the sign structure were not sheared or broke. However, this DCWS faces south and is also located within an open area that is typical of central Minnesota. In this case the winds were high (e.g., 40 or 50 mph), but not considered unusual in this area of Minnesota. It can only be speculated that the vibrations and/or slight movements caused by the winds in this area had produced a situation where the sign structure and bolts separated. At the time the McLeod County DCWS fell the signs in Meeker County, Minnesota remained in place and were checked again for any problems. None were found and they continue to operate. The DCWS in McLeod County fell after the last vehicle speed data collection proposed for this research project was completed. It was not reinstalled.

Based on what is described above, the application of the sign support structure used during this research project needs to be evaluated more closely when combined with this particular DCWS in similar climatological and geographical situations. For example, the characteristics of the DCWS and installation specifics, along with the incidence of high winds and significant weather events, should be considered in detail. There are also alternative sign support structures that can be used in these situations and others.

Summary of Findings

This chapter described the methodology and factors considered for the evaluation, comparison, and selection process of various dynamic signs during the national DSFS demonstration study. The results of this process were used in this research project in order to potentially supplement the analysis and conclusions of the national DSFS demonstration study. Overall, two signs were selected for evaluation by the national DSFS demonstration study team, and the Minnesota project team decided to install the curve display sign. This sign is the DCWS shown in Figure 4.1. Three of these DCWSs were purchased and then installed in May 2010. The DCWS were installed by county highway department staff and the challenges encountered both before and during the installation are described in this chapter. Many of the challenges encountered were related to the equipment needed to install this DCWS and the suggested sign support structure. The lack of experience all local transportation agencies would have with this type of installation was also a challenge. The pre-installation challenges described in this chapter were overcome during this research project, but additional post-installation challenges were also experienced. At two of the three study sites the sign posts appeared to slip out of their bases and the signs subsequently fell to the ground. At one study site this occurred during an unusual weather event, but in the second case it was during what might be considered to a typical high wind event in central Minnesota. It appeared to the project team that the vibrations and slight movement caused by the wind at the sign installation locations, along with sign and sign support characteristics, may have resulted in the posts separating from their bases. It is proposed by the project team that the adequacy of the sign support structure be evaluated very closely when used with this particular DCWS in similar climatological and geographical areas. Alternative sign support structures are available.

Chapter 5. Vehicle Speed Data Collection and Analysis

Three horizontal curve approaches were selected as study sites for this research project. Their selection and location are described in the last chapter. Bidirectional vehicle speed data were collected, using a pneumatic tube automatic traffic recorder, at three locations within each study sites. These locations were the visually identified PC of horizontal curve (and the location of the DCWS), a "within curve" point, and a "control" on the approach tangent which was typically ¼ to ½ mile from the DCWS (or visually identified PC). The 'within curve" location was included in this project to explore, if possible, the potential impacts of the DCWS on downstream vehicle speeds. The "control" location, on the other hand, was included in the vehicle speed data collection to help approximate the "background" changes in vehicle speeds from one data collection time period to another (e.g. one month before the DCWS installation to one year after). The distance from the visually identified PC (and location of the DCWS) to the "within curve" and "control" data collection locations within each study site varied. The specific distances for study site are noted in this chapter.

Overall, two to five days of vehicle speed data were collected approximately one month before and then approximately one month, six months, 1 year, and 18 months after the installation of the DCWS at each study site. This chapter includes descriptive statistics of the vehicle speed data collected during each before-and-after time period. These statistics include the minimum, maximum, average, 85th percentile, and standard deviation of the vehicle speeds collected. An analysis of the vehicle speed data was also completed. The focus of this analysis, however, was the speed of vehicles traveling into the horizontal curve at the visually identified PC or DCWS location. This is the primary traffic flow and data collection location of interest for this research project and it should experience the largest of any potential DCWS vehicle speed impacts. The average vehicle speed at the visually identified PC one month before the installation of the DCWS was statistically compared to the same measures during each data collection time period after the installation of the DCWS (i.e., one month, six months, one year, and 18 months). The magnitude of any changes or differences in the average vehicle speeds at this location was also explored with an informal investigation and description of how they might be impacted by the variation in average vehicle speed at the control location. A similar analysis was also completed for the average speed of vehicles traveling into the horizontal curve at the "within curve" data collection location. Lastly, the change in the percentage of vehicles traveling into the horizontal curve at the PC data collection that were 5, 10, 15, and 20 mph above either the posted or advisory speed limits are described. The chapter concludes with a summary of the crash data collected at each study site.

Vehicle Speed Data Descriptive Statistics

As indicated above, vehicle speed data are collected in each direction at three locations within each study site. The vehicle speed data collected for two to five days were used after a few adjustments. First, any questionable vehicle speed data were removed. For this project, questionable data were defined as any unclassified vehicles, vehicles where the software indicated no time gap between it and the previous vehicle, and those vehicles with calculated speeds equal to or more than 100 mph. The exclusion of the latter data did not impact the results as there were only four vehicles in this category during all the data collection time periods. The

first and last three hours of vehicle speed data collected were also removed from consideration, along with any data collected on the weekend and/or holidays. The exclusion of data from the beginning and end of the data collection efforts was done to eliminate the potential vehicle speed impacts of the research team setting up and removing the automatic traffic recording equipment. The weekend and any holiday data (e.g., July 5, 2010) were also removed to eliminate any potential vehicle speed impacts that might occur due to changes in traveling patterns during those time periods. Finally, it should also be noted that all the vehicle speed data collected (after the above adjustments) were included in the following summaries and analyses (See Tables 5.1 to 5.18) and they may not all be free-flow vehicles. In other words, it is possible that some of the individual vehicle speeds that were collected could have been influenced by other vehicles on the roadway. It is assumed for this project, however, that the low volumes along the study site roadways would result in a very small number of non-free-flow vehicle speeds and it is expected that the proportion of free-flow and non-free-flow vehicles would remain similar before and after the installation of the DCWS. A preliminary review of the data at the study site with the highest ADT (i.e., CSAH 7) supported the first of this assumption. The vehicle speed data collected one month before and one month, six months, one year, and 18 months after the installation of the DCWSs are summarized below.

One Month "Before" DCWS Installation

Vehicle speed data were collected approximately one month before the DCWS installation dates (May 19 and 20, 2010). This activity was completed from April 5, 2010 to April 9, 2010 at the CSAH 25 study site; April 12, 2010 to April 16, 2010 on CSAH 3 study site; and April 19, 2010 to April 23, 2010 on CSAH 7 study site.

The raw vehicle speed data collected by the automatic traffic recorder during the time periods above were adjusted and descriptive statistics calculated. These descriptive statistics are summarized in Tables 5.1 to 5.3. They include, by direction of traffic flow, the size of the database used for the calculations (i.e., the number of vehicle speeds), the maximum and minimum vehicle speeds observed, the average vehicle speed, and the 85th percentile vehicle speed. The vehicle speed standard deviation is also shown.

Overall, a total of 477 to 529 vehicle speeds were collected in each direction within the CSAH 25 study site about one month before the DCWS installation (See Table 5.1). The useable vehicle speeds collected ranged from 11 to 94 mph. The average vehicle speed was the highest at the control point. In the southbound (or primary) direction of travel the average and 85th percentile vehicle speeds at the PC were 53.4 and 59.3 mph, respectively. At the "within curve" location, however, these two southbound vehicle speed statistics increased to 56.2 and 63.2 mph. An increase in vehicle speeds (in this case 2.8 and 3.9 mph) from the PC to a location within a horizontal curve is not generally typical, but it does occur. These increases are also well within the variability of the data collected (see the standard deviations in Table 5.1). Overall, the standard deviation of the vehicle speeds ranged from 6.51 to 8.49 mph. The northbound vehicle speed data follow a more typical pattern with the average and 85th percentile vehicle speeds increasing as the vehicle exits the horizontal curve. The focus of this project and the analysis described later in this chapter, however, are the potential impacts of the DCWS on the speed of vehicles traveling into the horizontal curve (the primary direction of travel in Table 5.1) at the study site.

Table 5.1: One Month "Before" Vehicle Speed Descriptive Statistics – CSAH 25[1]

Statistic	Southbound (Primary Direction)		
	Control Point (Approx. 2640 Feet North)	**North Point of Curvature**	**Within Curve (By Approx. 400 Feet)**
Database Size	477	515	502
Minimum Vehicle Speed (mph)[2]	20	25	18
Maximum Vehicle Speed (mph)[2]	94	75	81
Average Vehicle Speed (mph)	57.6	53.4	56.2
85th Percentile Vehicle Speed (mph)	64.4	59.3	63.2
Standard Deviation (mph)	8.49	6.62	8.27
	Northbound (Secondary Direction)		
Database Size	492	528	525
Minimum Vehicle Speed (mph)[2]	21	25	11
Maximum Vehicle Speed (mph)[2]	75	73	64
Average Vehicle Speed (mph)	57.8	55.1	50.3
85th Percentile Vehicle Speed (mph)	63.6	61.0	55.7
Standard Deviation (mph)	7.35	6.66	6.51

[1]The primary direction of travel statistics are for vehicles traveling toward the proposed DCWS and into the horizontal curve. North point of curvature is the visually identified proposed location of the DCWS.
[2]Outlier and questionable vehicle speeds and those 100 mph or more (n = 0) were not included in this summary.

Overall, a total of 427 to 557 vehicle speeds were collected at the three locations within the CSAH 3 study site about one month before the DCWS installation (See Table 5.2). The useable vehicle speeds collected ranged from 10 to 84 mph. The average vehicle speed was the highest at the control point. In the eastbound (or primary) direction of travel the average and 85th percentile vehicle speeds at the PC were 53.9 and 61.8 mph, respectively. These vehicle speeds, however, were only 51.5 and 59.3 mph, respectively, at the "within curve" location. A reduction in vehicle speeds is typical as a vehicle enters a horizontal curve, but the horizontal curve at this study site also includes an access point that may impact the data collected. The westbound vehicle speed data, on the other hand, follow a less typical pattern and the average and 85th percentile vehicle speeds decrease by 0.7 and 0.5 mph, respectively, between the "within curve" and PC data collection locations. These decreases, however, are well within the variability of the data collected (see the standard deviations in Table 5.2). Overall, the standard deviation of the vehicle speeds collected ranged from 7.34 to 9.15 mph. It should also be noted that the

horizontal curve signs at this location are actually for a combination of two short large radii changes in alignment separated by a tangent section. This layout constitutes a "broken-back" horizontal curve and the "within curve" data collection location was near the west end of the tangent between the changes in alignment. The focus of this project and the analysis described later in this chapter are the potential impacts of the DCWS on the speed of vehicles traveling into (the primary direction of travel in Table 5.2) the horizontal curve at the study site.

Table 5.2: One Month "Before" Vehicle Speed Descriptive Statistics – CSAH 3[1]

	Eastbound (Primary Direction)		
Statistic	**Control Point (Approx. 5000 Feet West)**	**West Point of Curvature**	**Within Curve (By Approx. 275 Feet)**
Database Size	557	440	436
Minimum Vehicle Speed (mph)[2]	31	12	10
Maximum Vehicle Speed (mph)[2]	84	77	76
Average Vehicle Speed (mph)	57.7	53.9	51.5
85th Percentile Vehicle Speed (mph)	64.1	61.8	59.3
Standard Deviation (mph)	7.94	8.83	9.15
	Westbound (Secondary Direction)		
Database Size	514	436	427
Minimum Vehicle Speed (mph)[2]	19	11	14
Maximum Vehicle Speed (mph)[2]	74	68	68
Average Vehicle Speed (mph)	54.0	47.3	48.0
85th Percentile Vehicle Speed (mph)	60.3	54.6	55.1
Standard Deviation (mph)	7.34	8.68	8.41

[1]The primary direction of travel statistics are for vehicles traveling toward the proposed DCWS and intro the horizontal curve. The west point of curvature is the visually identified proposed location of the DCWS.
[2]Outlier and questionable vehicle speeds and those 100 mph or more (n = 0) were not included in this summary.

Overall, a total of 1,555 to 1,663 vehicle speeds were collected within the CSAH 7 study site about one month before the DCWS installation (See Table 5.3). The useable vehicle speeds collected ranged from 6 to 90 mph. The average vehicle speed was the highest at the control point. In the northbound (or primary) direction of travel the average and 85th percentile vehicle speeds at the PC were 55.8 and 61.3 mph, respectively. These vehicle speed descriptive statistics, however, were only 52.0 and 57.7 mph, respectively, at the "within curve" location. A

reduction in vehicle speeds is typical as a vehicle enters a horizontal curve. The southbound vehicle speed data, however, follow a less typical pattern and the average and 85th percentile vehicle speeds decrease as the vehicles exit the horizontal curve. More specifically, the average and 85th percentile southbound vehicle speeds decrease from 53.5 and 59.3 mph, respectively, at the "within curve" location to 53.1 and 57.7 mph, respectively, at the PC (a difference of 0.4 and 1.6 mph). These reductions, however, are well within the variability of the data collected (see the standard deviation in Table 5.3). Overall, the standard deviation of the vehicle speeds collected ranged from 6.34 to 8.01 mph. As noted previously, however, the focus of this project and the analysis described later in this chapter are the potential impacts of the DCWS on the speed of vehicles traveling into (the primary direction of travel in Table 5.3) the horizontal curve at the study site.

Table 5.3: One Month "Before" Vehicle Speed Descriptive Statistics – CSAH 7[1]

	Northbound (Primary Direction)		
Statistic	**Control Point (Approx. 2500 Feet South)**	**South Point of Curvature**	**Within Curve (By Approx. 500 Feet)**
Database Size	1,608	1,659	1,652
Minimum Vehicle Speed (mph)[2]	19	15	13
Maximum Vehicle Speed (mph)[2]	90	87	78
Average Vehicle Speed (mph)	59.3	55.8	52.0
85th Percentile Vehicle Speed (mph)	64.1	61.3	57.7
Standard Deviation (mph)	6.84	7.06	7.39
	Southbound (Secondary Direction)		
Database Size	1,555	1,606	1,599
Minimum Vehicle Speed (mph)[2]	14	6	14
Maximum Vehicle Speed (mph)[2]	86	74	74
Average Vehicle Speed (mph)	56.6	53.1	53.5
85th Percentile Vehicle Speed (mph)	60.8	57.7	59.3
Standard Deviation (mph)	6.42	6.34	8.01

[1]The primary direction of travel statistics are for vehicles traveling toward the proposed DCWS and into the horizontal curve. The south point of curvature is the visually identified proposed location of the DCWS.
[2]Outlier and questionable vehicle speeds and those 100 mph or more (n = 2) were not included in this summary.

One Month "After" DCWS Installation

Vehicle speed data were collected approximately one month after the DCWS installation dates (May 19 and 20, 2010). This activity was completed from June 13, 2010 to June 18, 2010 at the CSAH 25 study site and from June 20, 2010 to June 25, 2010 at the CSAH 3 study site. There were two time periods of data collection at the CSAH 7 sign location. First, vehicle speed data were collected at the control and "within curve" locations from June 27, 2010 to July 2, 2010. Then, vehicle speed data from the control point and the PC (i.e., the DCWS location) were collected from July 6, 2010 to July 10, 2010. This split in data collection at CSAH 7 was necessary because a roadside mower negatively impacted the initial data collection setup at the PC.

The raw vehicle speed data collected by the automatic traffic recorder during the time periods above were adjusted and descriptive statistics calculated. These descriptive statistics are summarized in Tables 5.4 to 5.6. They include, by direction of traffic flow, the size of the database used for the calculations (i.e., the number of vehicle speeds), the maximum and minimum vehicle speeds observed, the average vehicle speed, and the 85th percentile vehicle speed. The vehicle speed standard deviation is also shown.

Overall, a total of 714 to 830 vehicle speeds were collected in each direction at the three locations within the CSAH 25 study site about one month after the DCWS installation (See Table 5.4). The useable vehicle speeds collected ranged from 11 to 88 mph. The average vehicle speed was the highest at the control point. In the southbound (or primary) direction of travel the average and 85th percentile vehicle speeds at the PC were 51.7 and 58.4 mph, respectively. At the "within curve" location, however, these two southbound vehicle speed statistics increased to 51.9 and 59.0 mph. An increase in vehicle speeds (in this case 0.2 and 0.6 mph, respectively) from the PC to a location within a horizontal curve is not generally typical, but it does occur. These increases are also well within the variability of the data collected (i.e., see the standard deviations in Table 5.4). Overall, the standard deviation of the vehicle speeds collected ranged from 7.03 to 8.48 mph. The northbound vehicle speed data follow a more typical pattern with the average and 85th percentile vehicle speeds increasing as the vehicles exit the horizontal curve. The focus of this project and the analysis described later in this chapter, however, are the potential impacts of the DCWS on the speed of vehicles traveling into (the primary direction of travel in Table 5.4) the horizontal curve at the study site PC location.

Overall, a total of 638 to 967 vehicle speeds were collected in each direction within the CSAH 3 study site about one month after the installation of the DCWS (See Table 5.5). The useable vehicle speeds collected ranged from 12 to 97 mph. The average vehicle speed was the highest at the control point. In the eastbound (or primary) direction of travel the average and 85th percentile vehicle speeds at the PC were 48.2 and 53.9 mph, respectively. These vehicle speeds, however, were 47.9 and 54.2 mph, respectively, at the "within curve" location. They are essentially equal at the PC and "within curve" data collection points. A reduction in speed as a vehicle traverses a horizontal curve is often more typical. The westbound vehicle speed data follow a similar pattern and the differences between the "within curve" and PC average and 85th percentile vehicle speeds were 0 and 0.1 mph, respectively. Overall, the standard deviation of the vehicle speeds collected in both directions along CSAH 3 ranged from 7.01 to 8.84 mph.

The focus of this project and the analysis described later in this chapter, however, are the potential impacts of the DCWS on the speed of vehicles traveling into (the primary direction of travel in Table 5.2) the horizontal curve at the study site.

Table 5.4: One Month "After" Vehicle Speed Descriptive Statistics – CSAH 25[1]

	Southbound (Primary Direction)		
Statistic	**Control Point (Approx. 2640 Feet North)**	**North Point of Curvature**	**Within Curve (By Approx. 400 Feet)**
Database Size	714	753	768
Minimum Vehicle Speed (mph)[2]	20	18	17
Maximum Vehicle Speed (mph)[2]	85	73	72
Average Vehicle Speed (mph)	57.3	51.7	51.9
85th Percentile Vehicle Speed (mph)	64.1	58.4	59.0
Standard Deviation (mph)	8.48	7.31	8.05
	Northbound (Secondary Direction)		
Database Size	773	820	830
Minimum Vehicle Speed (mph)[2]	11	11	11
Maximum Vehicle Speed (mph)[2]	88	80	75
Average Vehicle Speed (mph)	57.8	53.5	51.2
85th Percentile Vehicle Speed (mph)	63.6	59.1	56.8
Standard Deviation (mph)	7.41	7.04	7.03

[1]The primary direction of travel statistics are for vehicles traveling toward the DCWS and into the horizontal curve. The north point of curvature is the location of the DCWS.
[2]Questionable data and outlier vehicle speeds and those 100 mph or more (n = 0) were not included in this summary.

The CSAH 7 study site vehicle speed data collection activities approximately one month after the DCWS installation were completed during two time periods (due to some issues with roadside mowing activities). The data from these two time periods are indicated by "No. 1" and "No. 2" in Table 5.6. Only data from the same time periods can be compared.

Overall, a total of 1,798 to 2,051 vehicle speeds were collected at the three locations within the CSAH 7 study site about one month after the installation of the DCWS (See Table 5.6). The useable vehicle speeds collected ranged from 10 to 90 mph. The average vehicle speed was the

highest at the control point. In the northbound (or primary) direction of travel the average and 85th percentile vehicle speeds at the point of curvature were 53.4 and 58.4 mph, respectively.

Table 5.5: One Month "After" Vehicle Speed Descriptive Statistics – CSAH 3[1]

	Eastbound (Primary Direction)		
Statistic	**Control Point (Approx. 5000 Feet West)**	**West Point of Curvature**	**Within Curve (By Approx. 275 Feet)**
Database Size	967	645	656
Minimum Vehicle Speed (mph)[2]	12	16	13
Maximum Vehicle Speed (mph)[2]	85	80	83
Average Vehicle Speed (mph)	55.4	48.2	47.9
85th Percentile Vehicle Speed (mph)	62.4	53.9	54.2
Standard Deviation (mph)	8.84	7.01	7.78
	Westbound (Secondary Direction)		
Database Size	916	639	638
Minimum Vehicle Speed (mph)[2]	19	21	16
Maximum Vehicle Speed (mph)[2]	97	70	75
Average Vehicle Speed (mph)	54.9	49.8	49.9
85th Percentile Vehicle Speed (mph)	61.7	57.0	57.1
Standard Deviation (mph)	8.10	7.93	8.29

[1]The primary direction of travel statistics are for the vehicles traveling toward the DCWS and into the horizontal curve. The west point of curvature is the location of the DCWS.
[2]Questionable data and outlier vehicle speeds and those 100 mph or more (n = 0) were not included in this summary.

These vehicle speed descriptive statistics, however, were 2 mph lower at the "within curve" location. Unfortunately, this comparison is not valid because the data are from two different time periods (See Table 5.6). A reduction in vehicle speed, however, is typical as a vehicle enters a horizontal curve. The southbound vehicle speed data, however, do appear to follow a relatively typical pattern for horizontal curves. The average and 85th percentile vehicle speeds increase or remain almost the same as the vehicles exit the horizontal curve. Again, however, these vehicle speeds were collected during different time periods and their comparison is not valid. In all cases the differences found are also well within the variability of the data collected (i.e., see the standard deviations in Table 5.6). Overall, the standard deviation of the vehicle speeds collected ranged from 5.17 to 7.41 mph. The focus of this project and the analysis

described later in this chapter are the potential impacts of a DCWS on the speed of vehicles traveling into (the primary direction of travel in Table 5.6) the horizontal curve at the study site.

Table 5.6: One Month "After" Vehicle Speed Descriptive Statistics – CSAH 7[1,2]

	Northbound (Primary Direction)		
Statistic	**Control Point (Approx. 2500 Feet South)**	**South Point of Curvature**	**Within Curve (By Approx. 500 Feet)**
Database Size	2,038 (No. 1) 1,849 (No. 2)	1,860 (No. 2)	2,051 (No. 1)
Minimum Vehicle Speed (mph)[3]	14 (No. 1) 11 (No. 2)	15 (No. 2)	12 (No. 1)
Maximum Vehicle Speed (mph)[3]	88 (No. 1) 85 (No. 2)	69 (No. 2)	68 (No. 1)
Average Vehicle Speed (mph)	58.2 (No. 1) 60.6 (No. 2)	53.4 (No. 2)	51.3 (No. 1)
85th Percentile Vehicle Speed (mph)	62.6 (No. 1) 65.0 (No. 2)	58.4 (No. 2)	56.3 (No. 1)
Standard Deviation (mph)	6.18 (No. 1) 6.02 (No. 2)	5.67 (No. 2)	6.55 (No. 1)
	Southbound (Secondary Direction)		
Database Size	2,028 (No. 1) 1,853 (No. 2)	1,798 (No. 2)	2,024 (No. 1)
Minimum Vehicle Speed (mph)[3]	17 (No. 1) 15 (No. 2)	10 (No. 2)	15 (No. 1)
Maximum Vehicle Speed (mph)[3]	90 (No. 1) 82 (No. 2)	89 (No. 2)	77 (No. 1)
Average Vehicle Speed (mph)	58.9 (No. 1) 56.9 (No. 2)	56.3 (No. 2)	55.3 (No. 1)
85th Percentile Vehicle Speed (mph)	62.8 (No. 1) 60.6 (No. 2)	60.6 (No. 2)	60.8 (No. 1)
Standard Deviation (mph)	5.81 (No. 1) 5.17 (No. 2)	5.65 (No. 2)	7.41 (No. 1)

[1]The primary direction of travel statistics are for vehicles traveling toward the DCWS and into the horizontal curve. The south point of curvature is the location of the DCWS.
[2]The data at this study site were collected during two time periods due to some issues with roadside mowing activities. The data from the two time periods are indicated by a "No. 1" and a "No. 2". Only the data collected during the same time periods should be compared.
[3]Questionable data and outlier vehicle speeds and those 100 mph or more (n = 1) were not included in this summary.

Six Months "After" DCWS Installation

Vehicle speed data were collected approximately six months after the DCWS installation dates (May 19 and 20, 2010). This activity was completed from November 16, 2010 to November 19, 2010 at the CSAH 25 study site; November 7, 2010 to November 10, 2010 at the CSAH 3 study site; and November 10, 2010 to November 12, 2010 at the CSAH 7 study site. These data

collection time periods were somewhat shorter than those previously used for this project due to the potential for significant snowfall and plowing activities. The data collection equipment used during this project can't be used when snow plowing is expected.
The raw vehicle speed data collected by the automatic traffic recorder during the time periods above were adjusted and descriptive statistics calculated. These descriptive statistics are summarized in Tables 5.7 to 5.9. They include, by direction of traffic flow, the size of the database used for the calculations (i.e., the number of vehicle speeds), the maximum and minimum vehicle speeds observed, the average vehicle speed, and the 85th percentile vehicle speed. The vehicle speed standard deviation is also shown.

Overall, a total of 325 to 420 vehicle speeds were collected at the three locations within the CSAH 25 study site (See Table 5.7). The useable vehicle speeds collected ranged from 12 to 86 mph. The average vehicle speed was the highest at the control point. In the southbound (or primary) direction of travel the average and 85th percentile vehicle speeds at the PC were 50.3 and 56.3 mph, respectively. At the "within curve" location, however, these two vehicle speed statistics increased to 52.9 and 59.0 mph. An increase in vehicle speeds (in this case 2.6 and 2.7 mph) from the PC to a location within a horizontal curve is not typical, but it does occur. These increases are also well within the variability of the data collected (i.e., see the standard deviations in Table 5.7). Overall, the standard deviation of the vehicle speeds collected in both directions ranged from 5.48 to 7.58 mph. The northbound vehicle speed data follow a more typical pattern with the average and 85th percentile vehicle speeds increasing as the vehicles exit the horizontal curve. The focus of this project and the analysis described later in this chapter are the potential impacts of the DCWS on the speed of vehicles traveling into (the primary direction of travel in Table 5.7) the horizontal curve at the study site.

Overall, a total of 312 to 374 vehicle speeds were collected at the three locations within the CSAH 3 study site (See Table 5.8). The useable vehicle speeds collected ranged from 13 to 77 mph. The average vehicle speed was typically the highest at the control points. The one exception to this pattern was the westbound "within curve" average vehicle speed. This measure, and the coinciding 85th percentile vehicle speed, "within" the curve were 1.2 mph and 3.0 mph higher than those at the control location. Although unexpected, the vehicles at the control point and within the horizontal curve are somewhat different (i.e., there is an intersection with another county highway between the two data collection points) and the vehicle speeds at the "within curve" location are highly variable (i.e., a standard deviation of 9.85 mph). In addition, all the differences calculated are well within the variability of the data (see the standard deviations in Table 5.8). In the eastbound (or primary) direction the average and 85th percentile vehicle speeds at the PC were 46.1 and 51.4 mph, respectively. These vehicle speeds, however, were 49.7 and 57.3 mph, respectively, at the "within curve" location. The "within curve" vehicle speeds are 3.6 and 6.1 mph higher than at the PC, and although an increase in vehicle speeds from the PC to a location within a horizontal curve is not typical, these increases are within the variability of the data collected (i.e., see the standard deviations in Table 5.8). As noted above the westbound vehicle speed data also follow a less than typical pattern and the average and 85th percentile vehicle speeds decrease by 3.5 and 4.5 mph, respectively, between the "within curve" and PC data collection locations. These decreases are somewhat unexpected, but they do follow a pattern similar to (but with a larger magnitude) that found in the vehicle speed data collected before the DCWS installation. They are also within the variability of the data collected (i.e., see

the standard deviations in Table 5.8). Overall, the standard deviation of the vehicle speeds collected ranged from 6.32 to 9.85 mph. The focus of this project and the analysis described later in this chapter are the potential impacts of the DCWS on the speed of vehicles traveling into (the primary direction of travel in Table 5.8) the horizontal curve at the study site.

Table 5.7: Six Months "After" Vehicle Speed Descriptive Statistics – CSAH 25[1]

Statistic	Southbound (Primary Direction)		
	Control Point (Approx. 2640 Feet North)	**North Point of Curvature**	**Within Curve (By Approx. 400 Feet)**
Database Size	325	344	345
Minimum Vehicle Speed (mph)[2]	29	30	19
Maximum Vehicle Speed (mph)[2]	78	71	74
Average Vehicle Speed (mph)	57.5	50.3	52.9
85th Percentile Vehicle Speed (mph)	64.6	56.3	59.0
Standard Deviation (mph)	7.54	6.26	7.06
	Northbound (Secondary Direction)		
Database Size	397	419	420
Minimum Vehicle Speed (mph)[2]	30	31	12
Maximum Vehicle Speed (mph)[2]	86	77	64
Average Vehicle Speed (mph)	58.2	53.9	48.1
85th Percentile Vehicle Speed (mph)	64.0	58.8	52.6
Standard Deviation (mph)	7.58	6.21	5.48

[1]The primary direction of travel statistics are for vehicles traveling toward the DCWS and into the horizontal curve. The north point of curvature is the location of the DCWS.
[2]Questionable data and outlier vehicle speeds and those 100 mph or more (n =1) were not included in this summary.

Overall, a total of 689 to 726 vehicle speeds were collected at the three locations within the CSAH 7 study site (See Table 5.9). The useable vehicle speeds collected ranged from 10 to 89 mph. The average vehicle speed was the highest at the control point. In the northbound (or primary) direction of travel the average and 85th percentile vehicle speeds at the point of curvature were 52.0 and 57.3 mph, respectively. These vehicle speed descriptive statistics were 3.2 and 3.6 mph higher, however, at the "within curve" location. These differences are within the variability of the data (see the standard deviations in Table 5.9), but a reduction in speed is more typical as a vehicle enters a horizontal curve. Overall, the standard deviation of the vehicle

speeds collected in both directions ranged from 6.23 to 6.99 mph. The southbound vehicle speed data follow a more typical pattern and the average and 85th percentile vehicle speeds increase as the vehicles exit the horizontal curve. The focus of this project and the analysis described later in this chapter are the potential impacts of the DCWS on the speed of vehicles traveling into (the primary direction of travel in Table 5.9) the horizontal curve at the study site.

Table 5.8: Six Months "After" Vehicle Speed Descriptive Statistics – CSAH 3[1]

	Eastbound (Primary Direction)		
Statistic	**Control Point (Approx. 5000 Feet West)**	**West Point of Curvature**	**Within Curve (By Approx. 275 Feet)**
Database Size	374	326	326
Minimum Vehicle Speed (mph)[2]	18	19	13
Maximum Vehicle Speed (mph)[2]	77	62	69
Average Vehicle Speed (mph)	53.2	46.1	49.7
85th Percentile Vehicle Speed (mph)	59.6	51.4	57.3
Standard Deviation (mph)	8.01	6.32	8.75
	Westbound (Secondary Direction)		
Database Size	353	312	316
Minimum Vehicle Speed (mph)[2]	20	19	15
Maximum Vehicle Speed (mph)[2]	74	68	73
Average Vehicle Speed (mph)	49.5	47.2	50.7
85th Percentile Vehicle Speed (mph)	55.4	53.9	58.4
Standard Deviation (mph)	7.72	7.89	9.85

[1]The primary direction of travel statistics are for the vehicles traveling toward the DCWS and into the horizontal curve. The west point of curvature is the location of the DCWS.
[2]Questionable data and outlier vehicle speeds and those 100 mph or more (n = 0) were not included in this summary.

One Year "After" DCWS Installation

Vehicle speed data were collected approximately one year after the DCWS installation dates (May 19 and 20, 2010). This activity was completed from July 25, 2011 to July 29, 2011 at the CSAH 25 study site; May 16, 2011 to May 23, 2011 at the CSAH 3 study site, and from July 18, 2011 to July 25, 2011 at the CSAH 7 study site. When reviewing the data it is also important to take into account an unexpected event at the CSAH 25 study site. On March 23, 2011 the DCWS at the CSAH 25 study site fell during a severe winter event (e.g., high winds and heavy

snow). The DCWS was reinstalled on June 20, 2011. Therefore, the vehicle speeds collected at CSAH 25, while presented here, should not be considered representative of those that might be expected one year after the installation of a DCWS. The drivers approaching this location likely adjusted their driving to account for the three month absence of the DCWS. The time period of readjustment for these drivers after the reinstallation of the DCWS is unknown but it appears to be longer than one month (i.e., the usefulness of the vehicle speed data collected at CSAH 25 "one year" after the initial installation is questionable).

Table 5.9: Six Months "After" Vehicle Speed Descriptive Statistics – CSAH 7[1]

	Northbound (Primary Direction)		
Statistic	**Control Point (Approx. 2500 Feet South)**	**South Point of Curvature**	**Within Curve (By Approx. 500 Feet)**
Database Size	719	726	722
Minimum Vehicle Speed (mph)[2]	17	10	26
Maximum Vehicle Speed (mph)[2]	89	75	80
Average Vehicle Speed (mph)	58.8	52.0	55.2
85th Percentile Vehicle Speed (mph)	63.0	57.3	60.9
Standard Deviation (mph)	6.46	6.23	6.72
	Southbound (Secondary Direction)		
Database Size	700	702	689
Minimum Vehicle Speed (mph)[2]	16	15	15
Maximum Vehicle Speed (mph)[2]	81	77	73
Average Vehicle Speed (mph)	59.2	54.5	52.5
85th Percentile Vehicle Speed (mph)	64.0	59.5	58.0
Standard Deviation (mph)	6.99	6.49	6.94

[1]The primary direction of travel statistics are for vehicles traveling toward the DCWS and into the horizontal curve. The south point of curvature is the location of the DCWS.
[2]Questionable data and outlier vehicle speeds and those 100 mph or more (n = 0) were not included in this summary.

The raw vehicle speed data collected by the automatic traffic recorder during the time periods noted were adjusted and descriptive statistics calculated. These descriptive statistics are summarized in Tables 5.10 to 5.12. They include, by direction of traffic flow, the size of the database used for the calculations (i.e., the number of vehicle speeds), the maximum and

minimum vehicle speeds observed, the average vehicle speed, and the 85th percentile vehicle speed. The vehicle speed standard deviation is also shown.

Overall, a total of 566 to 709 vehicle speeds were collected at the three locations within the CSAH 25 study site (See Table 5.10). The useable vehicle speeds collected ranged from 13 to 86 mph. The average vehicle speed was the highest at the control point. In the southbound (or primary) direction of travel the average and 85th percentile vehicle speeds at the PC were 54.5 and 61.5 mph, respectively. At the "within curve" location, however, these two southbound vehicle speed descriptive statistics decreased to 52.5 and 60.0 mph. A decrease in vehicle speeds from the PC to a location within a horizontal curve is typical, but is not always observed given the variability in the vehicle speed data. Overall, the standard deviation of the vehicle speeds collected ranged from 6.72 to 8.61 mph. The northbound average and 85th percentile vehicle speeds were approximately the same at the "within curve" location and as the vehicles exited at the PC (they were within 0.7 mph of each other). Typically, an increase in vehicle speeds occurs as the vehicles exit a horizontal curve rather than the slight reduction (i.e., 0.2 and 0.7 mph) observed. The focus of this project and the analysis described later in this chapter, however, are the potential impacts of the DCWS on the speed of vehicles traveling into (the primary direction of travel in Table 5.10) the horizontal curve at the study site.

Overall, a total of 709 to 891 vehicle speeds were collected at the three locations within the CSAH 3 study site (See Table 5.11). The useable vehicle speeds collected ranged from 7 to 82 mph. The average vehicle speed was the highest at the control point in the eastbound direction, but actually the lowest in the westbound direction. It is unknown why this pattern occurred in the westbound direction. However, the vehicles at the control point and at the horizontal curve are somewhat different and the vehicle speeds at this study site are also highly variable (see the standard deviations in Table 5.11). In the eastbound (or primary) direction the average and 85th percentile vehicle speeds at the PC were 45.1 and 51.0 mph, respectively. These vehicle speeds, however, were 45.2 and 52.4 mph, respectively, at the "within curve" location. These "within curve" speeds are similar (i.e., with only a 0.1 to 1.4 mph difference) to those at the PC. A reduction in vehicle speed is more typical. These differences, however, are all well within the variability of the data collected. The westbound vehicle speed data follow a similar pattern with the vehicle speeds within the horizontal curve being slightly higher than those at the PC. The differences between the "within curve" and PC average and 85th percentile vehicle speeds, however, are only 0.3 and 0.7 mph, respectively. These differences are also well within the variability of the data collected (see the standard deviations in Table 5.11). Overall, the standard deviation of the vehicle speeds collected in both directions ranged from 7.01 to 9.83 mph. The focus of this project and the analysis described later in this chapter, however, are the potential impacts of the DCWS on the speed of vehicles traveling into (the primary direction of travel in Table 5.11) the horizontal curve at the study site.

Overall, a total of 2,505 to 2,779 vehicle speeds were collected at the three locations within the CSAH 7 study site (See Table 5.12). The useable vehicle speeds collected ranged from 9 to 97 mph. The average vehicle speed was the highest at the control point. In the northbound (or primary) direction of travel the average and 85th percentile vehicle speeds at the PC were 52.2 and 57.2 mph, respectively. These vehicle speed descriptive statistics at the "within curve" location, however, are 0.1 mph lower and 0.2 mph greater, respectively, than those calculated for

the PC location. A reduction in speed is typical as a vehicle enters a horizontal curve but in this case it remains essentially equal at the "within curve" and PC data collection locations. The differences calculated are also well within the standard deviation of the vehicle speed data collected (See the standard deviations in Table 5.12).

Table 5.10: One Year "After" Vehicle Speed Descriptive Statistics – CSAH 25[1,2]

	Southbound (Primary Direction)		
Statistic	**Control Point (Approx. 2640 Feet North)**	**North Point of Curvature**	**Within Curve (By Approx. 400 Feet)**
Database Size	566	584	587
Minimum Vehicle Speed (mph)[3]	15	13	13
Maximum Vehicle Speed (mph)[3]	84	77	78
Average Vehicle Speed (mph)	55.1	54.5	52.5
85th Percentile Vehicle Speed (mph)	62.0	61.5	60.0
Standard Deviation (mph)	8.61	7.73	8.19
	Northbound (Secondary Direction)		
Database Size	677	709	706
Minimum Vehicle Speed (mph)[3]	14	13	14
Maximum Vehicle Speed (mph)[3]	86	67	68
Average Vehicle Speed (mph)	59.3	52.0	52.2
85th Percentile Vehicle Speed (mph)	65.1	57.3	58.0
Standard Deviation (mph)	8.13	6.72	7.21

[1]Overall, the vehicle speed data summarized in this table were collected approximately one month after the reinstallation of the DCWS at this study site (after a three month absence). The data are considered highly questionable. See the text under the "One Year "After" DCWS Installation" heading for more explanation.
[2]The primary direction of travel statistics are for vehicles traveling toward the DCWS and into the horizontal curve. The north point of curvature is the location of the DCWS.
[3]Questionable data and outlier vehicle speeds and those 100 mph or more (n = 0) were not included in this summary.

The southbound vehicle speed data follow a pattern similar to that observed in the northbound direction. The average and 85th percentile southbound vehicle speeds at the "within curve" location are essentially equal to those calculated for the PC. In fact, the average and 85th percentile southbound vehicle speeds at the "within curve" location are only 0.3 mph lower and 0.1 mph greater, respectively, than those calculated for the PC. An increase in vehicle speed is

typical as a vehicle exits a horizontal curve but in this case the descriptive statistics were essentially unchanged. These differences, of course, are also well within the standard deviation of the vehicle speed data collected (see the standard deviations in Table 5.12). Overall, the standard deviation of the vehicle speeds collected at CSAH 7 ranged from 5.62 to 7.68 mph. The focus of this project and the analysis described later in this chapter are the potential impacts of a DCWS on the speed of vehicles traveling into (the primary direction of travel in Table 5.12) the horizontal curve at the study site.

Table 5.11: One Year "After" Vehicle Speed Descriptive Statistics – CSAH 3[1]

	Eastbound (Primary Direction)		
Statistic	**Control Point (Approx. 5000 Feet West)**	**West Point of Curvature**	**Within Curve (By Approx. 275 Feet)**
Database Size	891	709	710
Minimum Vehicle Speed (mph)[2]	12	19	12
Maximum Vehicle Speed (mph)[2]	82	70	81
Average Vehicle Speed (mph)	54.3	45.1	45.2
85th Percentile Vehicle Speed (mph)	61.8	51.0	52.4
Standard Deviation (mph)	8.98	7.35	9.69
	Westbound (Secondary Direction)		
Database Size	885	757	755
Minimum Vehicle Speed (mph)[2]	15	7	8
Maximum Vehicle Speed (mph)[2]	79	79	78
Average Vehicle Speed (mph)	49.5	52.4	52.7
85th Percentile Vehicle Speed (mph)	55.6	61.1	61.8
Standard Deviation (mph)	7.01	9.83	11.2

[1]The primary direction of travel statistics are for vehicles traveling toward the DCWS and into the horizontal curve. The west point of curvature is the location of the DCWS.
[2]Questionable data and outlier vehicle speeds and those 100 mph or more (n = 0) were not included in this summary.

Eighteen Months "After" DCWS Installation

Vehicle speed data were collected approximately one year after the DCWS installation dates (May 19 and 20, 2010). This activity was completed from October 31, 2011 to November 2, 2011 at the CSAH 25 study site; October 24, 2011 to October 26, 2011 at the CSAH 3 study site, and from October 17, 2011 to October 19, 2011 at the CSAH 7 study site. These data collection

time periods are shorter than normal because of a problem that occurred with the automatic traffic recorder after about two days. It is also still important to take into account that the data collected at the CSAH 25 study site may be influenced by the fact that the DCWS fell on March 23, 2011 and was then reinstalled on June 20, 2011 (more explanation of the potential impacts of this situation is in the last section of this report). However, in general it appears that the vehicle speeds collected are more similar to what was observed before the DCWS fell. The drivers may have readjusted, but still may not truly represent what would have occurred 18 month after the DCWS installation if there had not been a need for reinstallation.

Table 5.12: One Year "After" Vehicle Speed Descriptive Statistics – CSAH 7[1]

	Northbound (Primary Direction)		
Statistic	**Control Point (Approx. 2500 Feet South)**	**South Point of Curvature**	**Within Curve (By Approx. 500 Feet)**
Database Size	2,505	2,572	2,563
Minimum Vehicle Speed (mph)[2]	11	12	12
Maximum Vehicle Speed (mph)[2]	97	72	71
Average Vehicle Speed (mph)	61.0	52.2	52.1
85th Percentile Vehicle Speed (mph)	66.2	57.2	57.4
Standard Deviation (mph)	7.27	6.33	6.88
	Southbound (Secondary Direction)		
Database Size	2,638	2,770	2,779
Minimum Vehicle Speed (mph)[2]	15	9	10
Maximum Vehicle Speed (mph)[2]	97	80	83
Average Vehicle Speed (mph)	59.2	55.3	55.0
85th Percentile Vehicle Speed (mph)	63.2	60.6	60.7
Standard Deviation (mph)	5.62	6.80	7.68

[1]The primary direction of travel statistics are for vehicles traveling toward the DCWS and into the horizontal curve. The south point of curvature is the location of the DCWS.
[2]Questionable data and outlier vehicle speeds and those 100 mph or more (n = 0) were not included in this summary.

The raw vehicle speed data collected by the automatic traffic recorder during the time periods above was adjusted and descriptive statistics calculated. These descriptive statistics are summarized in Tables 5.13 to 5.15. They include, by direction of traffic flow, the size of the database used for the calculations (i.e., the number of vehicle speeds), the maximum and

minimum vehicle speeds observed, the average vehicle speed, and the 85th percentile vehicle speed. The vehicle speed standard deviation is also shown.

Overall, a total of 222 to 274 vehicle speeds were collected in each direction at the three locations within the CSAH 25 study site (See Table 5.13). The useable vehicle speeds collected ranged from 27 to 85 mph. The average vehicle speed was typically the highest at the control point. The one exception was that it was in the northbound direction. In this case the average vehicle speed calculated at the PC was higher than that at the control point. This is unusual for this study site and the average and 85th percentile speeds in the northbound direction at the PC location are slightly higher than one standard deviation of the data from these same measures in previous data collection time periods. Therefore, while unusual, it can and does occur. The vehicle speed data for this direction of travel are also not the focus of this project and will not be analyzed. In the southbound (or primary) direction of travel the average and 85th percentile vehicle speeds at the PC were 52.4 and 57.9 mph, respectively. At the "within curve" location, however, these two southbound vehicle speed descriptive statistics increased to 55.0 and 61.1 mph. An increase in vehicle speeds (in this case 2.6 and 3.2 mph) from the PC to the "within a curve" location is not generally typical, but this type of increase has been observed at this study site during past data collection time periods and is also well within the variability of the data collected (see the standard deviations in Table 5.13). Overall, the standard deviation of the vehicle speeds collected in both directions ranged from 5.80 to 8.25 mph. The northbound average and 85th percentile vehicle speeds follow a typical vehicle speed pattern and increase from the "within curve" location to the PC. However, as noted above the northbound vehicle speed data at the PC are somewhat unusual. The focus of this project and the analysis described later in this chapter, however, are the potential impacts of a DCWS on the speed of vehicles traveling into (the primary direction of travel in Table 5.13) the horizontal curve at the study site.

Table 5.13: Eighteen Months "After" Vehicle Speed Descriptive Statistics – CSAH 25[1,2]

Statistic	Southbound (Primary Direction)		
	Control Point (Approx. 2640 Feet North)	**North Point of Curvature**	**Within Curve (By Approx. 400 Feet)**
Database Size	222	233	230
Minimum Vehicle Speed (mph)[3]	27	23	20
Maximum Vehicle Speed (mph)[3]	84	69	75
Average Vehicle Speed (mph)	59.6	52.4	55.0
85th Percentile Vehicle Speed (mph)	65.9	57.9	61.1
Standard Deviation (mph)	8.25	6.08	6.85
	Northbound (Secondary Direction)		
Database Size	266	274	274
Minimum Vehicle Speed (mph)[3]	32	37	34
Maximum Vehicle Speed (mph)[3]	82	85	70
Average Vehicle Speed (mph)	56.2	59.6	53.7
85th Percentile Vehicle Speed (mph)	61.3	65.9	59.1
Standard Deviation (mph)	6.17	6.97	5.80

[1]Overall, the vehicle speed data summarized in this table were collected approximately seven months after the reinstallation of the DCWS at this study site (after a three month absence). The data may not represent what would have occurred without the DCWS absence and reinstallation. See the text under the "Eighteen Months "After" DCWS Installation" heading for more explanation.

[2]The primary direction of travel statistics are for vehicles traveling toward the DCWS and into the horizontal curve. The north point of curvature is the location of the DCWS.

[3]Questionable data and outlier vehicle speeds and those 100 mph or more (n = 0) were not included in this summary.

Overall, a total of 191 to 289 vehicle speeds were collected at the three locations within the CSAH 3 study site (See Table 5.14). The useable vehicle speeds collected ranged from 13 to 89 mph. The average vehicle speed was the highest at the control point in the eastbound direction, but there is also some concern about the vehicle speed data collected at the control location. The average and 85th percentile vehicles speeds in this direction are about one standard deviation of the data from these same measures in previous data collection time periods. Therefore, while unusual, this type of difference can and does occur. The average westbound vehicle speed at the control point, on the other hand, is 0.1 mph lower than that calculated at the PC. It is unknown why this pattern is occurring in the westbound direction, but was also observed at this study site during the one year "after" data collection. In addition, although unexpected, the vehicles at the

control point and at the horizontal curve are somewhat different and the vehicle speeds at this study site are highly variable (see the standard deviations in Table 5.14). In the eastbound (or primary) direction the average and 85th percentile vehicle speeds at the PC were 48.4 and 54.3 mph, respectively. These vehicle speeds, however, were 49.7 and 56.9 mph, respectively, at the "within curve" location. These "within curve" speeds are similar (i.e., with only a 0.7 to 2.6 mph difference) to those at the PC, but a reduction in speed as a vehicle exists a horizontal curve is more typical. This type of change, however, has been observed before at this study site and the differences are well within the variability of the data collected. It was also noted in the field that the pneumatic tubes connected to the automatic traffic recorder had shifted somewhat during the data collection time period. The average and 85th percentile vehicle speeds at the "within curve" location, however, are well within the variability of the data collected (see Table 5.14). The westbound vehicle speed data follow a typical pattern and increase as the vehicles exit the horizontal curve at the PC location. Overall, the standard deviation of the vehicle speeds collected in both directions ranged from 6.61 to 9.66 mph. The focus of this project and the analysis described later in this chapter are the potential impacts of a DCWS on the speed of vehicles traveling into (the primary direction of travel in Table 5.14) the horizontal curve at the study site.

Overall, a total of 956 to 1,017 vehicle speeds were collected at the three locations within the CSAH 7 study site (See Table 5.15). The useable vehicle speeds collected ranged from 14 to 94 mph. The average vehicle speed was the highest at the control location. The average and 85th percentile vehicle speeds in each direction at the control location are about one standard deviation of the data from these same measures in previous data collection time periods. Therefore, while unusual, it can and does occur. In the northbound (or primary) direction the average and 85th percentile vehicle speeds at the PC were 53.6 and 59.9 mph, respectively.

Table 5.14: Eighteen Months "After" Vehicle Speed Descriptive Statistics – CSAH 3[1]

Statistic	Eastbound (Primary Direction)		
	Control Point (Approx. 5000 Feet West)	**West Point of Curvature**	**Within Curve (By Approx. 275 Feet)**
Database Size	284	193	191
Minimum Vehicle Speed (mph)[2]	19	19	13
Maximum Vehicle Speed (mph)[2]	89	67	71
Average Vehicle Speed (mph)	60.8	48.4	49.7
85th Percentile Vehicle Speed (mph)	68.8	54.3	56.9
Standard Deviation (mph)	9.66	7.34	9.03
	Westbound (Secondary Direction)		
Database Size	289	209	211
Minimum Vehicle Speed (mph)[2]	32	24	14
Maximum Vehicle Speed (mph)[2]	84	68	63
Average Vehicle Speed (mph)	51.5	51.6	47.1
85th Percentile Vehicle Speed (mph)	56.4	58.5	53.4
Standard Deviation (mph)	6.61	8.11	8.37

[1]The primary direction of travel statistics are for vehicles traveling toward the DCWS and into the horizontal curve. The west point of curvature is the location of the DCWS.
[2]Questionable data and outlier vehicle speeds and those 100 mph or more (n = 0) were not included in this summary.

These vehicle speed descriptive statistics at the "within curve" location, however, are 3.7 mph and 4.5 mph lower than those calculated for the PC. A reduction in speed is typical as a vehicle enters a horizontal curve, but this was only been observed at this study site during the one month "before" installation time period. In addition, the differences that were calculated are well within the standard deviation of the vehicle speed data collected (see the standard deviations in Table 5.15). The southbound vehicle speed data follow a less typical pattern. The average and 85th percentile southbound vehicle speeds decrease from the "within curve" to PC data collection locations (i.e., as vehicles exit the horizontal curve). The differences are a decrease in average and 85th percentile vehicle speeds of 1.4 and 2.4 mph, respectively. A similar pattern in vehicle speeds was observed at this location before the DCWS was installed and these differences are also within the variability of the vehicle speed data collected (see the standard deviations in Table 5.15). Overall, the standard deviation of the vehicle speeds collected at the CSAH 7 study site ranged from 5.41 to 7.60 mph. The focus of this project and the analysis described later in

this chapter are the potential impacts of a DCWS on the speed of vehicles traveling into (the primary direction of travel in Table 5.15) the horizontal curve at the study site.

Table 5.15: Eighteen Months "After" Vehicle Speed Descriptive Statistics – CSAH 7[1]

	Northbound (Primary Direction)		
Statistic	**Control Point (Approx. 2500 Feet South)**	**South Point of Curvature**	**Within Curve (By Approx. 500 Feet)**
Database Size	956	980	972
Minimum Vehicle Speed (mph)[2]	16	17	14
Maximum Vehicle Speed (mph)[2]	81	84	70
Average Vehicle Speed (mph)	55.2	53.6	49.9
85th Percentile Vehicle Speed (mph)	58.8	59.9	55.4
Standard Deviation (mph)	5.41	7.02	7.00
	Southbound (Secondary Direction)		
Database Size	998	1017	1010
Minimum Vehicle Speed (mph)[2]	18	23	16
Maximum Vehicle Speed (mph)[2]	94	77	76
Average Vehicle Speed (mph)	61.9	54.8	56.2
85th Percentile Vehicle Speed (mph)	66.5	59.9	62.3
Standard Deviation (mph)	6.93	6.15	7.60

[1]The primary direction of travel statistics are for vehicles traveling toward the DCWS and into the horizontal curve. The south point of curvature is the location of the DCWS.
[2]Questionable data and outlier vehicle speeds and those 100 mph or more (n = 0) were not included in this summary.

Before and After Average Vehicle Speed Comparisons

The primary objective of this research project was to investigate the potential vehicle speed impacts of DCWSs. A DCWS was installed at one visually identified PC within each of study sites. The vehicle speed data for traffic flow traveling toward the DCWS and into the horizontal curve was summarized in the previous section of this chapter. The potential vehicle speed impact of the DCWSs was evaluated by calculating the difference between the average vehicle speed for this traffic flow one month before and one month, six months, one year, and 18 months

after the installation of the DCWS. A simple t-test (assuming a normal distribution of data and unequal variances) was then applied to determine whether these differences were statistically significant (with a 95 percent level of confidence). These analyses were completed for the average vehicle speed calculated for vehicles traveling into the horizontal curve at the visually identified PC (i.e., the DCWS installation site) and "within curve" data collection locations of each study site. The difference in the average vehicle speeds and the results of the t-test comparisons are summarized in the following paragraphs, Tables 5.16 and 5.17, and Figures 5.1 and 5.2. These before-and-after differences in average vehicle speed were also adjusted for the changes observed in average vehicle speed at the control location within each study site. These adjustments were applied to consider the potential influence of general background shifts in vehicle speeds from data collection time period to another. Qualitative conclusions about the impact of these adjustments are noted.

Table 5.16 includes the differences calculated in average vehicle speed at the visually identified PC (for traffic flow traveling toward the DCWS and into the horizontal curve) before and after the installation of the DCWS for each data collection time period. The differences in average vehicle speed at the control location for the same direction of travel and time period comparisons are also summarized. Finally, the statistical significance (at a 95 percent level of confidence) of each difference is also noted. Table 5.17 contains similar information for the "within curve" vehicle speed data location at each study site.

At the CSAH 25 study site the primary direction of travel is southbound. Table 5.16 summarizes the differences calculated between the average vehicle speed at the visually identified PC data collection location one month before and one month, six months, one year, and 18 months after the DCWS installation. These differences are also plotted in Figure 5.1. The difference calculated range from a reduction in average vehicle speed of -1.7 mph to an increase of +1.1 mph (See Table 5.16). It is important to note, however, that the DCWS fell at this study site and had to be reinstalled (after a three month absence) about one month before what is noted as the "one month before to one year after" comparison in Table 5.16. It was concluded that the vehicle speed data collected during this particular time period was clearly not representative of "one year after" the DCWS installation and it was speculated that it more likely measuring an adjustment period of drivers to the reinstallation of the sign. The trends in the differences in average vehicle speed support these conclusions and are described below. The differences in the average vehicle speeds at the location of the DCWS before it fell, for example, indicate a reduction of -1.7 and -3.1 mph one month and six months after the initial installation (See Table 5.16). These reductions also occurred when the change in average vehicle speed at the control location was essentially zero (See Table 5.16). In addition, the "one month before to 18 months after" comparison of average vehicle speeds revealed a -1.0 mph reduction at the DCWS location and this decrease occurred while the average vehicle speed at the control location increased by +2.0 mph. It would appear, therefore, that the average vehicle speed impact (adjusted for the changes observed at the control location) of the DCWS at its installation site may have been about -3.0 mph six months after its initial installation and then about seven months after it was reinstalled (i.e., about 18 months after the initial installation). The average vehicle speed about a month after the reinstallation (i.e., the "one month before to one year after" comparison in Table 5.16), on the other hand, was actually +1.1 mph greater than that calculated one month before the DCWS installation and this occurred even as the average vehicle speed at the control location

decreased by -2.5 mph. It would appear, therefore, that the data collected one month after the reinstallation of the sign were not representative of the potential vehicle speed impacts of a DCWS one year after its installation. The data collected during this time period more likely represent some type of readjustment of the drivers to the reinstallation of the DCWS.

The average vehicle speed reduction at the CSAH 25 "within curve" study site location ranged from -1.2 to -4.3 mph (see Table 5.17 and Figure 5.2) and the differences appear to decrease from one month to after months after the installation of the DCWS. The reductions in average vehicle speed at the visually identified PC (see Table 5.16) and the "within curve" locations (see Table 5.17) of the study site, when adjusted for the changes in the average vehicle speed at the control location, are about -3.0 to -3.2 mph, respectively, 18 months after the initial installation of the DCWS.

At the CSAH 3 study site the primary direction of travel is eastbound. Table 5.16 summarizes the differences calculated between the average vehicle speed at the visually identified PC data collection location one month before and one month, six months, one year, and 18 months after the DCWS installation. These differences are also plotted in Figure 5.1. The differences in the average vehicle speed at the visually identified PC (which is also the DCWS location) range from -5.5 to -8.8 mph (see Table 5.16), and they appear to increase from one month after the DCWS installation to one year (see Figure 5.1). The magnitude of the before-and-after difference in average vehicle speed 18 months after the installation of DCWS, however, is approximately equal to that calculated one month after the installation. If these changes in the average vehicle speed are adjusted for those occurring at the control location of the study site (which are assumed to represent background changes in vehicle speed) the reductions at the visually identified PC appear to range from -3.3 to -8.6 mph and generally increase with time. Overall, the average vehicle speeds at the control location generally experienced smaller reductions than those observed at the visually identified PC, but eighteen months after the DCWS installation a -5.5 mph reduction in average vehicle speed was calculated for the visually identified PC location and a +3.1 mph increase occurred at the control location.

The average vehicle speed reductions at the CSAH 3 "within curve" study site location range from -1.8 to -6.3 mph (see Figure 5.2) and do appear to follow any type of pattern. The before-and-after average vehicle speed changes at the "within curve" location were larger than those observed at the control point for some time periods and smaller for others. When adjusted for the changes in average vehicle speed at the control location, therefore, the differences in the average vehicle speed at the "within curve" location range from a reduction of -4.9 mph (18 months after the DCWS installation) to an increase of+ 2.7 mph (six months after the DCWS installation). However, except for the +2.7 mph increase, the adjusted reductions in average vehicle speed at the "within curve location" appear to increase with time. The vehicle speed data at the "within curve" location were highly variable and these results are likely a measure of that characteristic. Overall, the reductions in average vehicle speeds at the visually identified PC (see Table 5.16) and the "within curve" locations (see Table 5.17) of the study site, when adjusted for changes in the average vehicle speed at the control location, are about -8.6 mph and -4.9 mph, respectively, 18 months after the installation of the DCWS.

Table 5.16: Average Vehicle Speed Differences at the Visually Identified PC (DCWS Installation) and Control Locations Before and After Sign Installation[1]

	Difference in Average Vehicle Speeds (mph)[2]									
Study Site and Primary Travel Direction	**One Month Before to One Month After (mph)**	**Statistically Significant?[3]**	**One Month Before to Six Months After (mph)**	**Statistically Significant?[3]**	**One Month Before to One Year After (mph)**	**Statistically Significant?[3]**	**One Month Before to 18 Months After (mph)**	**Statistically Significant?[3]**	**Control Location Differences (mph)[4]**	**Statistically Significant?[3]**
CSAH 25 Southbound	-1.7	Yes	-3.1	Yes	+1.1[5]	Yes[5]	-1.0[5]	No[5]	-0.3/-0.1/ -2.5/+2.0[5]	No/No/ Yes/ Yes[5]
CSAH 3 Eastbound	-5.7	Yes	-7.8	Yes	-8.8	Yes	-5.5	Yes	-2.3/-4.5/ -3.4/+3.1	Yes/Yes/ Yes/Yes
CSAH 7 Northbound	-2.4	Yes	-3.8	Yes	-3.6	Yes	-2.2	Yes	+1.3/-0.5/ +1.7/-4.1	Yes/No/ Yes/ Yes

[1]Primary direction of travel statistics are for vehicles traveling toward the DCWS and into the horizontal curve. PC = point of curvature.
[2]The difference is equivalent to one month, six months, one year, or 18 months "after" DCWS installation average vehicle speeds minus the one month "before" DCWS installation average vehicle speeds. Unless noted, all differences are for the visually identified point of curvature data collection location.
[3]Statistically significant to a 95 percent level of confidence based on a t-test assuming a normal distribution of data and unequal variances.
[4]The first number is the difference between average vehicle speeds one month "before" and one month "after" the DCWS installation. Second to fourth numbers represent similar calculations between one month "before" the DCWS installation and six months, one year, and 18 months after the installation.
[5]The vehicle speed data collected one year and 18 months after the initial DCWS installation date occurred only one month and seven months after the need to reinstall the CSAH 25 DCWS (after a three month absence). The reader is referred to the report text for more explanation of the meaning of these statistics. The "one month before to 18 months after" difference is not significant at a 95 percent level of confidence but is at 90 and 94 percent.

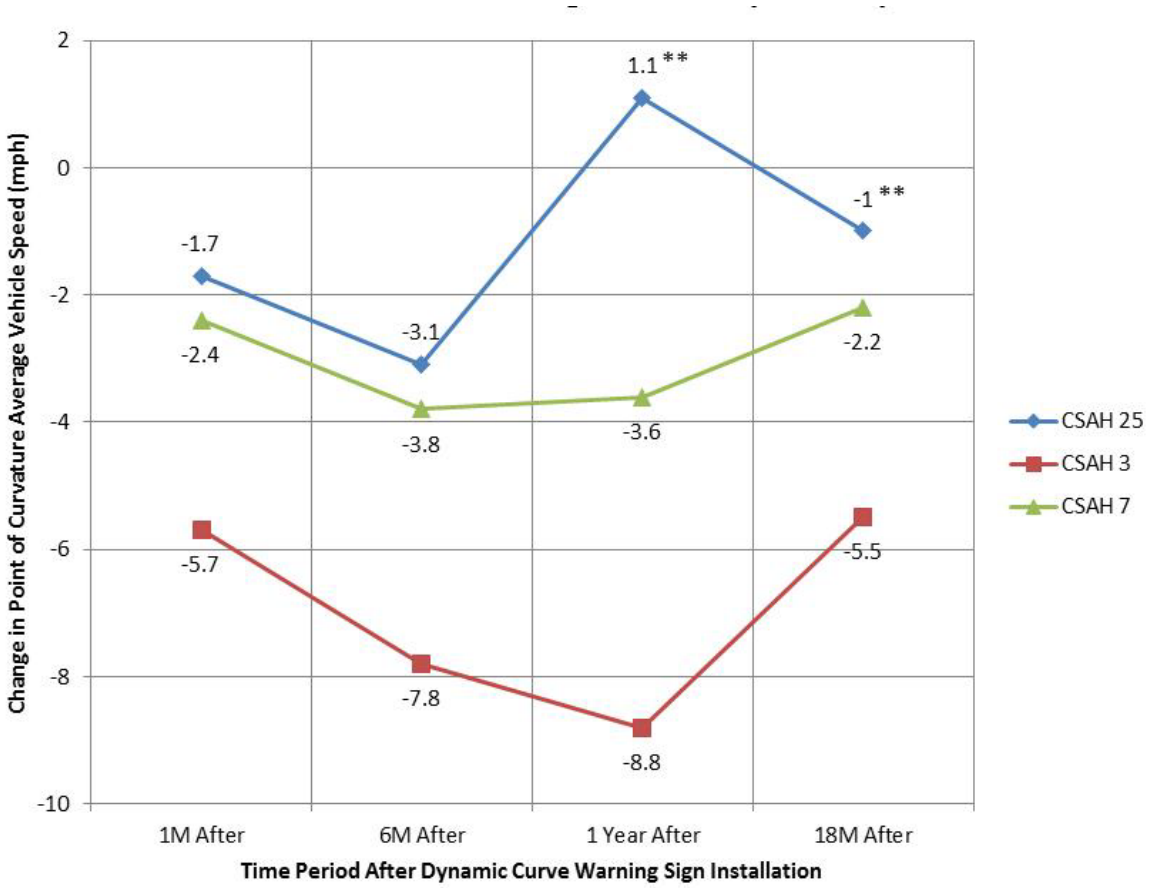

Figure 5.1: Differences in Visually Identified Point of Curvature Average Vehicle Speed between One Month before and Various Time Periods after the DCWS Installation (See footnote in Table 5.16 and text of the report)**

Table 5.17: Average Vehicle Speed Differences at "Within Curve" and Control Locations before and after Sign Installation[1]

	Difference in Average Vehicle Speeds (mph)[2]									
Study Site and Primary Travel Direction	**One Month Before to One Month After (mph)**	**Statistically Significant?[3]**	**One Month Before to Six Months After (mph)**	**Statistically Significant?[3]**	**One Month Before to One Year After (mph)**	**Statistically Significant?[3]**	**One Month Before to 18 Months After (mph)**	**Statistically Significant?[3]**	**Control Location Differences (mph)[4]**	**Statistically Significant?[3]**
CSAH 25 Southbound	-4.3	Yes	-3.3	Yes	-3.7[5]	Yes[5]	-1.2[5]	Yes[5]	-0.3/-0.1/ -2.5/+2.0[5]	No/No/ Yes/Yes[5]
CSAH 3 Eastbound	-3.6	Yes	-1.8	Yes	-6.3	Yes	-1.8	Yes	-2.3/-4.5/ -3.4/+3.1	Yes/Yes/ Yes/Yes
CSAH 7 Northbound	-0.7	Yes	+3.2	Yes	+0.1	No	-2.1	Yes	-1.0/-0.5/ +1.7/-4.1[6]	Yes/No/ Yes/ Yes

[1]Primary direction of travel statistics are for vehicles traveling toward the DCWS and into the horizontal curve.
[2]The difference is equivalent to one month, six months, one year, or 18 months "after" DCWS installation average vehicle speeds minus the one month "before" DCWS installation average vehicle speeds. Unless noted, all differences are for the "within curve" data collection location.
[3]Statistically significant to a 95 percent level of confidence based on a t-test assuming a normal distribution of data and unequal variances.
[4]The first number is the difference between average vehicle speeds one month "before" and one month "after" the DCWS installation. Second to fourth numbers represent similar calculations between one month "before" the DCWS installation and six months, one year, and 18 months after the installation.
[5]The vehicle speed data collected one year and 18 months after the initial DCWS installation date occurred only one month and seven months after the need to reinstall the CSAH 25 DCWS (after a three month absence). The reader is referred to the report text for more explanation of the meaning of these statistics.
[6]The control location difference between one month before and one month after the DCWS installation is different for CSAH 7 in Tables 5.16 and 5.17. The control location vehicle speeds collected for comparison to the PC and the "within curve" locations were collected on different dates.

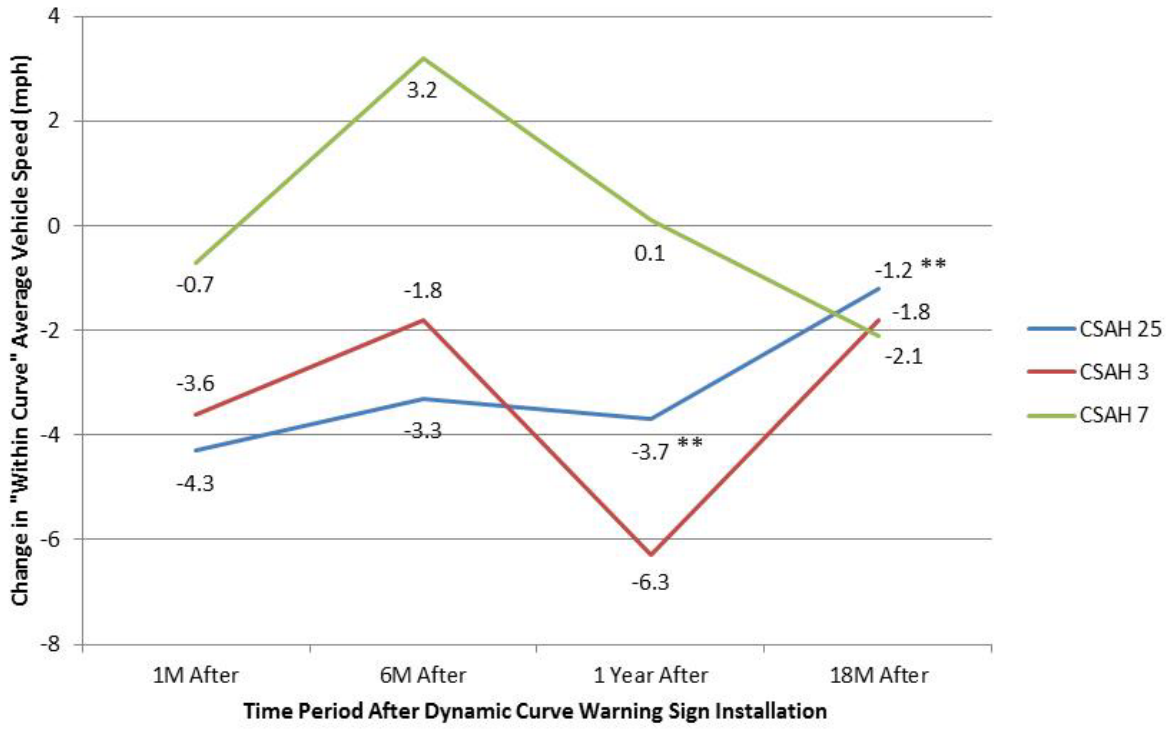

Figure 5.2: Differences in "Within Curve" Average Vehicle Speed between One Month before and Various Time Periods after the DCWS Installation (See footnote in Table 5.17 and text of the report.)**

At the CSAH 7 study site the primary direction of travel is northbound. Table 5.16 summarizes the differences calculated between the average vehicle speed at the visually identified PC data collection location one month before and one month, six months, one year, and 18 months after the DCWS installation. These differences are also plotted in Figure 5.1. The differences in average vehicle speed at the visually identified PC (which is also the DCWS location) range from -2.2 to -3.8 mph (see Table 5.16), and appear to increase from one month to six months and one year after the DCWS installation. The difference between the average vehicle speed before the DCWS installation and 18 months after (i.e., -2.2 mph), however, is about the same as that calculated for the time period one month after the installation (i.e., 2.4 mph). This trend in the average vehicle speed differences is shown in Figure 5.1. The differences, when adjusted for the changes in average vehicle speed at the CSAH 7 control location, however, are -3.7 mph one month after the DCWS installation, -3.3 mph six months after the DCWS installation, -5.3 mph one year after the DCWS installation, and +1.9 mph 18 months after the DCWS installation. It is unknown why the average vehicle speed at the CSAH 7 control location 18 months after the DCWS produced a greater before-and-after reduction than that calculated for the visually identified PC location or sign installation site. Overall, however, the control location at this study site experienced a wide range of increases and reductions in average vehicle speed (i.e., a +1.7 mph increase to a -4.1 mph reduction) (see Table 5.16).

The differences in average vehicle speed at the CSAH 7 "within curve" location for the various before and after comparisons were quite variable. The differences ranged from a decrease of

-2.1 mph (18 month after the DCWS installation) to an increase of 3.2 mph (one month after the DCWS installation) (See Figure 5.2). When these differences are adjusted for the changes observed in average vehicle speed at the control location they are also highly variable. They range from a -1.6 mph (one year after the DCWS installation) to an increase of +3.7 mph (one month after the DCWS installation). Similar calculations indicate a +0.3 mph increase in average vehicle speed one month after the DCWS installation and a +2.0 increase 18 months after. As noted above, however, changes in average vehicle speed at the control location were highly variable. In addition, the changes indicated are well within the variability of the vehicle speed data collected. The variability of the changes calculated at this study site "within curve" location could also be related to the radii of the horizontal curve, the existence of a county road intersection downstream of the data collection location but still within the horizontal curve, or possibly some compensation by drivers for the speed reduction at the sign location (see the discussion above). Overall, the changes in average vehicle speeds at the visually identified PC (see Table 5.16) and the "within curve" locations (see Table 5.17) of the study site, when adjusted for those at the control location, showed increases of about +1.9 mph and +2.0 mph, respectively, 18 months after the installation of the DCWS.

Percent Vehicles Traveling at or Above Posted or Advisory Speed

Table 5.18 summarizes the changes in the distribution of vehicle speeds above the posted or advisory speed at each study site. This objective of this summary was to evaluate whether the DCWSs may have had a larger proportional impact on vehicles traveling at higher speeds. A reduction in the number of vehicles traveling at speeds higher than the posted or advisory speeds, in theory, should have a greater safety improvement impact. Vehicles traveling at excessive speeds may be more likely to run off the roadway at a horizontal curve. Table 5.18 contains the difference in the percent of vehicles traveling 5, 10, 15, and 20 mph more than the posted or advisory speed from one month before the DCWS installation to one month, six months, one year, and 18 months after the installation. The percentage change in this measure for each comparison is also noted.

The posted speed at the CSAH 25 study site was 55 mph and there was no advisory speed. The overall average percent change (for all the time periods compared) ranged from -45.1 percent for vehicles traveling 5 mph or more than the posted speed limit to -76.7 percent for vehicles traveling 15 mph or more than the posted speed limit. There was no appreciable number of vehicles observed traveling 20 mph faster than the posted speed limit during any data collection time period (it was only 0.1 percent of vehicles one year after the installation). It is also important to note, however, that the overall averages calculated for the CSAH 25 study site did not include the statistics calculated for the "before to one year after" period. These data were actually collected one month after a reinstallation of the DCWS and appear to represent a time period of readjustment to the reinstallation of the DCWS rather than a "one year after" driver reaction. The impact of the DCWS on the number of vehicles at higher speeds, however, appears to be proportionally larger than those traveling speeds closer to the posted speed limit.

Table 5.18: Percent Difference and Percent Change of Vehicles Traveling at or Above Posted or Advisory Speed by the Amount Indicated (Percent Change = ((Measure after – Minus before)/(Measure before))*100)

	Percent Difference	Percent Change	Percent Difference	Percent Change	Percent Difference	Percent Change	Percent Difference	Percent Change
	Posted or Advisory +5 mph		**Posted or Advisory +10 mph**		**Posted or Advisory +15 mph**		**Posted or Advisory +20 mph**	
Study Site: CSAH 25, Primary Travel Direction: Southbound, Posted Speed = 55 mph								
Before to One Month After	-2.2	-19.1	-0.3	-16.4	-0.2	-48.7	0.0	0.0
Before to Six Months After	-8.7	-75.0	-0.9	-50.1	0.3	-81.3	0.0	0.0
Before to One Year After[1]	+10.8[1]	+92.5[1]	+2.9[1]	+164.6[1]	+0.5[1]	+120.5[1]	+0.1[1]	--[1]
Before to 18 Months After	-4.8	-41.1	-1.4	-80.4	-0.4	-100.0	0.0	0.0
Average[1]	-5.2[1]	-45.1[1]	-0.9[1]	-49.0[1]	-0.3[1]	-76.7[1]	0.0[1]	0.0[1]
Study Site: CSAH 3, Primary Travel Direction: Eastbound, Posted Advisory Speed = 40 mph								
Before to One Month After	-17.0	-20.2	-36.0	-51.6	-36.0	-75.8	-18.3	-81.4
Before to Six Months After	-26.3	-31.2	-45.2	-64.8	-43.8	-92.3	-22.2	-98.6
Before to One Year After	-31.0	-36.8	-50.4	-72.3	-42.7	-89.9	-21.1	-93.7
Before to 18 Months After	-15.9	-18.9	-30.9	-44.3	-34.0	-71.6	-17.1	-75.8
Average	-22.6	-26.8	-40.6	-58.2	-39.1	-82.4	-19.7	-87.4
Study Site: CSAH 7, Primary Travel Direction: Northbound, Posted Advisory Speed = 50 mph								
Before to One Month After	-23.6	-38.7	-16.5	-69.7	-1.8	-76.5	-0.5	-100.0
Before to Six Months After	-33.7	-55.4	-19.8	-83.2	-1.7	-75.9	-0.2	-42.9
Before to One Year After	-31.1	-51.1	-20.1	-84.8	-1.7	-76.2	-0.4	-86.6
Before to 18 Months After	-20.5	-33.6	-9.1	-38.1	+0.6	+24.7	-0.1	-15.4
Average	-27.2	-44.7	-16.4	-68.9	-1.2	-51.0	-0.3	-61.2

[1]Overall average does not include measures from one year after installation. DCWS was reinstalled one month before these measures and is believed to represent a driver adjustment period rather than a "one year after" reaction. CSAH 25 had no vehicles traveling +20 mph or more above the posted speed limit and only 0.1 percent during the "one year after" data collection time period.

The advisory speed limit at the CSAH 3 study site was 40 mph. The overall average percent change (for all the time periods compared) ranged from -26.8 percent for vehicles traveling 5 mph or more than the advisory speed limit to -87.4 percent for vehicles traveling 20 mph or more than the advisory speed limit. Once again, the proportional impact of the DCWS on the number of vehicles traveling at higher speeds appears to be larger than those traveling at speeds closer to the advisory speed limit.

The advisory speed limit at the CSAH 7 study site was 50 mph. The overall average percent change (for all the time periods compared) ranged from -44.7 percent for vehicles traveling 5 mph or more than the advisory speed limit to -61.2 percent for vehicles traveling 20 mph or more than the advisory speed limit. The trend of the average percent change at this study site, however, appears to be relatively constant. The largest percent change, for example, is in the number of vehicles traveling 10 mph or more above the posted advisory speed (n = -68.9 percent) and this is higher than the percent change in vehicles traveling 15 mph or more and 20 mph or more above the posted advisory speed limit (n = -51.0 percent and 61.2 percent, respectively). Overall, however, the apparent impact of the DCWS was the greatest at the CSAH 7 study site on the percentage of vehicles traveling 10 mph or more above the posted advisory speed (n = 68.9 percent).

Study Site Crash Data Comparison

The proposal for this project initially included a comparison of crash data before and after the installation of the DCWS at each study site. The same type of comparison was also proposed for three "control" study sites that were considered similar to the DCWS installation locations. Three years of vehicle crash data before the installation was to be collected and compared to as much as two years of data after the installation. As this project advanced, however, it became clear to the research team that this type of basic before and after comparison would not produce any results that could attributed to the installation of the DCWSs. The small number of low-volume roadway study sites (n = 3) and the small number of crashes at these sites were the primary reasons the research team concluded that this type of basic comparison should not be part of this project. In fact, it was also concluded that even documenting that these comparisons were valid and connected to the installation of the DCWS. Therefore, it was agreed that this task would not be completed and vehicle speed impacts would be the focus. Some of the other reasons for the removal of this task from this project include the following:

- The study sites for this project were horizontal curves along low-volume roadways. The occurrence of vehicle crashes along these roadways is rare and random. There are very few "high crash" locations. This fact does not mean, however, that there are no locations of safety concern (e.g., horizontal curves) along these low-volume roadways.
- The selection of candidate study sites for this project was based on a proactive safety improvement prioritization process. This process included a series of factors and crashes were just one (see below). The approach was different than that used in the national DSFS demonstration study. The national study based its initial candidate study site selection on "high crash" location identification results.
- The factors considered in the prioritization process and the study site selection included the occurrence of any crash within five years as one factor, but also included other factors that were equally weighted and helped define the potential for a safety problem at a

horizontal curve. Some of these surrogates of the safety risk at a horizontal curve included radii and the existence of a visual trap. This process could have resulted in the selection of a study site that had no crashes. The prioritization process used in this research project and the site selection results are described in Chapter 3.

- The selection of the study sites during this research project also included the use of vehicle speed data at the visually identified PC (and installation of the DCWSs). The national DSFS demonstration study defined horizontal curve locations of potential safety concern as those with a mean or 85th percentile vehicle speed at the visually identified PC that was 5 mph or more above the posted or advisory speed limit. Vehicle speed impacts were the focus of this research project and considered a surrogate measure for the potential safety of a horizontal curve location. It was the primary measure of effectiveness used in this research project.
- Horizontal curves have a higher density of crashes than rural roadway segments, but the study sites selected for this research project had only one to five total crashes during the five years considered in the prioritization process noted above (and used in selecting the candidate study sites). In addition, some portion these crashes are not likely to be impacted by a DCWS.

It has long been acknowledged that the lack of reported crashes on low-volume rural roadway horizontal curves does not necessarily mean they are "safe". The potential for a crash (due to the low traffic volumes) is just low. As noted above the study sites used in this research project had a low volume of traffic flow.

The national DSFS demonstration study had many more study sites and higher traffic volumes. It is possible however, that the crash data from the study sites used in this research project may be some value if they are combined with those from the national DSFS demonstration study. The inclusion of crash data from low-volume roadways in the national DSFS demonstration safety evaluation may improve their conclusions. The crash data below, therefore, is documented for used by the national DSFS demonstration project research team if they should need it.

The DCWSs were installed at the study sites used in this research project in May 2010. From 2002 to 2006, the years used to select the study site, CSAH 25 experienced one fatality, two "A" injury, and two "B" injury crashes. The CSAH 3 study site had only one "B" injury crash during that time period. There were no crashes, however, at either the CSAH 25 or the CSAH 3 study sites for the three years before the DCWS installation (i.e., April 2007 to April 2010). In addition, there were no crashes at these study sites from June 2010 to December 19, 2011 (the last month crash data were available). The prioritization process used to select the CSAH 7 study site, on the other hand, used crash data from 2003 to 2007. Two property damage crashes occurred during this time period at the CSAH 7 study site. However, there were no crashes at this study site from April 2007 to April 2010 or from June 2010 to December 19, 2011 (the last month crash data were available). Two conclusions can be drawn from the crash data summarized above. One, the crash data at these study sites are highly variable. The crash data used in the selection of the study sites was different than what has occurred both three years before the installation of the DCWS and for the 19 months following the installation. Two, the

value of the before-and-after crash data to either this research project or the national DSFS demonstration study is limited.

Summary of Findings

This chapter included a summary of the vehicle speed data collection and analysis activities completed as part of this project. First, vehicle speed descriptive statistics were summarized for both directions of travel at the three data collection locations within each of the three study sites. The changes in the average and 85th percentile vehicle speeds in each direction at the study sites were also described, but the focus of the discussion was the primary direction of travel (i.e., traffic flow into the horizontal curve) at the visually identified PC data collection location (and the DCWS installation site). Vehicle speed data descriptive statistics at the "within curve" and control data collection locations were also provided.

The average vehicle speeds at the study site visually identified PC (which is also the DCWS installation location) and "within curve" locations one month before and one month, six months, one year, and 18 months after the DCWS installation were compared. The significance of the differences calculated was statistically evaluated with a t-test and the results of these activities are described. The trends in the differences of the average vehicle speeds, between the data collection time periods, are also examined and summarized. A similar discussion of trends is completed at each study site for the differences in average vehicle speed after they are adjusted for the changes observed at the control data collection location. The changes in average vehicle speed at the control locations are assumed to represent the background adjustments in vehicle speed that may occur from one data collection time period to another. Similar data and trend analyses were also completed for the average vehicle speeds at the "within curve" data collection location of each study site.

An overall average of the differences in average vehicle speed (for all the data collection time periods) at each study site was calculated for this summary of findings. Overall, the average "before and after" differences in average vehicle speed (for all the data collection time periods) at the visually identified PC and "within curve" locations of the CSAH 25 study site were -1.9 and -2.9 mph, respectively. This study site, however, only had what were considered to be three valid before-and-after comparisons because four months before the "one year after" data collection time period the DCWS fell. It was reinstalled was actually only one month after a reinstallation of the DCWS (after a three month absence) and the "one year after" data collected one month later. The data collected during this time period appears to represent an adjustment period by drivers to the reinstallation. If vehicle speed data from all four before-and-after time periods were included in the calculations for the CSAH 25 study site average of the differences in the average vehicle speed at the visually identified PC and "within curve" locations would be -1.2 mph and -3.1 mph, respectively.

Comparisons similar to those described above were also done for the CSAH 3 and CSAH 7 study sites. The overall average difference in the average vehicle speeds at the visually identified PC and "within curve" locations at the CSAH 3 study site were -7.0 and -3.4 mph, respectively. Similarly, the overall average difference in the average vehicle speed differences at the visually identified PC and "within curve" locations at the CSAH 7 study site were -3.0 and +0.1 mph, respectively. Vehicle speeds at the "within curve" locations tend to be more variable than those

collected at the visually identified PC. Therefore, the differences found between the average vehicle speeds at the "within curve" locations were also more variable. It is also important to note, however, that the differences summarized above have not been adjusted for the changes in average vehicle speed that were observed at the control location of each study site. As noted previously, the changes in average vehicle speed at the control location are assumed to represent the background impacts on vehicle speed from one data collection time period to another. When adjusted for the shifts in average vehicle speed at the control location, the overall average difference in the average vehicle speeds at the visually identified PC and "within curve" locations of the CSAH 25 study site were -2.5 and -3.5 mph, respectively (for the three time periods data considered valid). The overall average differences also change to -5.2 and -1.6 mph at CSAH 3 and -2.6 and +1.1 mph at CSAH 7 after this same type of adjustment. In general, the adjustments increase the potential impact of the DCWS at the CSAH 25 study site, decrease it at the CSAH 3 study site, and have a mixed impact at the CSAH 7 study site (i.e., the impact at the visually identified PC is reduced, but it is increased at the "within curve" location). Finally, the unadjusted and adjusted differences in average vehicle speed between the one month before and 18 months after data collection time periods at the visually identified PC were -1.0 mph and -3.0 mph at CSAH 25, -5.5 mph and -8.6 mph at CSAH 3, and -2.2 mph and +1.9 mph at CSAH 7, respectively. At the "within curve" location of each study sites these same measures were -1.2 mph and -3.2 mph at CSAH 25, -1.8 mph and -4.9 mph at CSAH 3, and -2.1 mph and +2.0 mph at CSAH 7.

This chapter concluded with a summary of the percentage of vehicles traveling at least 5, 10, 15, and 20 mph faster than the posted or advisory speed limit at each study site. The differences in these percentages from one month before to one month, six month, one year, and 18 months after the DCWS was installed were calculated. In addition, the percent change for each time period was compared and an overall average determined. The overall average percent change at each study site generally showed that the impact of the DCWS was proportionally larger on vehicles traveling at higher speeds. In other words, the number of vehicles traveling at higher speeds seems to be reduced proportionally more than those traveling closer to the posted or advisory speed limits. These higher-speed vehicles are also those that are more likely to run off the road at a horizontal curve. Lastly, a brief summary is provided in this chapter about the number of crashes before and after the installation of the DCWS at the three study sites. In general, it was determined that no valid conclusions could be made about the direct crash reduction impact of the DCWSs at these study sites. The number of study sites (n = 3) and small to non-existent number of crashes at these low-volume study sites did not allow this type of comparison. The crash data provided in this chapter is only for use by the national DSFS demonstration study team if its application is helpful.

Chapter 6. Overall Findings and Recommendations

The primary objective of this project was to estimate the potential vehicle speed impacts of DCWSs at study sites along low-volume, local rural roadways. Overall, three locations were selected for the installation of a DCWS approximately 1.5 hours west of Minneapolis/St. Paul, Minnesota. Two of the study sites were at horizontal curves on CSAH 25 and CSAH 3 in Meeker County, Minnesota and third study site was at horizontal curve on CSAH 7 in McLeod County, Minnesota. This project included activities related to a review of the relevant literature, study site selection, the selection and installation of the DCWSs, vehicle speed data collection, and the summary and analysis of the vehicle speed data. The overall findings and recommendations based on the results of these tasks are documented below. Details about these findings and support for the recommendations can be found in Chapters 1 to 5.

Overall Findings

- The number of crashes on horizontal curves along local rural roadways is overrepresented. There is a need to address this safety concern. This project was designed to consider the potential vehicle speed impacts of DCWSs installed at horizontal curves along local rural roadways. In this case, the changes in the average vehicle speeds before and after the installation of the DCWS were considered a surrogate for safety and are the primary measure of effectiveness for evaluation. There is also an ongoing national DSFS demonstration study that is examining the potential vehicle speed impacts of a DCWS at study sites on rural two-lane highways. This project followed the protocols defined by this national study when appropriate, and the DCWS evaluated was also considered in the national DSFS demonstration study.

- Past research has shown that there are a number of physical and operational horizontal curve characteristics that impact vehicle speed and crashes. The change in vehicle speed required to negotiate a horizontal curve is one factor. The installation of traditional horizontal curve or turn signs does appear to produce a reduction in crashes. However, there is a limited amount of published research focused on the vehicle speed and/or crash impacts of DCWSs. Only a few of these studies appear to have had study sites within rural areas and/or along low-volume roadways. The published research does appear, however, to indicate that the installation of dynamic warning signs has some potential to reduce vehicle speed and crashes. This project and the ongoing national DSFS demonstration study were developed in response to the lack of significant published research in this area.

- The candidate study sites considered in this research project were the result of a proactive horizontal curve safety improvement prioritization process. This prioritization was completed in Meeker County before the start of this project and its results used. The prioritization in McLeod County, on the other hand, was done as part of this project. The factors considered in the prioritization for each county were essentially the same, but considered in a slightly different manner as the prioritization process was improved through time. Three of the factors considered for the prioritization of horizontal curves

were radius, the occurrence of a crash within five years, and existence of a visual trap. Required and desirable study site characteristics (many of which were those used in the national DSFS demonstration study), along with the prioritization results, were used to identify 4 to 6 viable study sites within each participating county. Vehicle speed data were then collected at the visually identified PC (which is also the proposed DCWS installation location) of each viable study site and the results compared to the national DSFS demonstration study definition of a location with potential vehicle speed concerns. A study site for this project needed to meet this definition to be selected. The three study sites selected from the list of viable locations were along CSAH 25 and CSAH 3 in Meeker County, Minnesota and CSAH 7 in McLeod County, Minnesota.

- The sign selection process and results used in the national DSFS demonstration study were also used in this study. One objective of this research project was to produce results that could be combined with those of the national DSFS demonstration study (if it was desired). Therefore, this project needed to evaluate one of the signs selected and considered by the research team of the ongoing national DSFS demonstration study. Overall, two signs were selected for evaluation in the national DSFS demonstration study and we selected the DCWS (See Figure 4.1). This DCWS was installed at three locations in May 2010. Most of the challenges encountered during the installation of the DCWSs were related to number of people and type of equipment needed to complete the activity. This type of sign and the sign support structure used for this project were not familiar to the participating county highway departments. All the challenges encountered, however, were overcome. Unfortunately, the support posts used to erect two of the DCWSs also separated from their slipbase supports in the last year. The first DCWS fell about 10 months after its initial installation during an unusual weather event. It was reinstalled three months later and the potential impact of this reinstallation on the vehicle speed data results are explained in this report. The second DCWS fell after the last data collection activity was completed and was not reinstalled. It was speculated that the relatively constant wind vibration and movement of the sign support structure may have been a contributing factor to these failures.

- Vehicle speeds were collected with a pneumatic automatic traffic recorder. These data were collected at three locations within each study site. These data collection locations were at a control point on the tangent approach (a ½ mile to mile from the DCWS), at the visually identified PC of the horizontal curve (which was also the DCWS location), and at a "within curve" location. The vehicle speed data collected were summarized with a series of descriptive statistics (i.e., average vehicle speed, 85th percentile vehicle speed, standard deviation, etc.) for both directions of traffic flow, but the focus of this research project was on speed of vehicles traveling in the primary direction of interest (i.e., the traffic flow toward the DCWS and into the horizontal curve) at the visually identified PC and "within curve" locations. Vehicle speed data were collected one month before and one month, six months, one year, and 18 months after the installation of the DCWSs.

- The difference in average vehicle speed before and after the installation of the DCWS was calculated for each data collection time period. The focus of the analysis completed for this project was the differences in the average vehicle speed at the visually identified

PC and "within curve" locations for the traffic flow into the horizontal curve. For discussion purposes these differences were also adjusted for the changes in average vehicle speeds observed at the control locations. It was assumed that the differences at the control locations were a measure of the potential background changes that can occur in vehicle speeds from one data collection time period to another. The overall average of the differences in average vehicle speeds at the CSAH 25 visually identified PC and "within curve" locations were -1.9 and -2.9 mph, respectively. These overall average differences change to -2.5 and -3.5 mph, however, if naively adjusted for the changes observed at the control location (Note that only three of the four data collection efforts completed after the installation of the DCWS at the CSAH 25 study site were considered valid. More information about why this is true is available in the report). The unadjusted and adjusted differences in average vehicle speeds one month before and 18 months after the installation of the DCWS at the visually identified PC of the CSAH 25 study site were -1.0 mph and -3.0 mph, respectively. At the "within curve" location of the CSAH 25 study site these same measures of average vehicle speed were -1.2 mph and -3.2 mph.

The average of the differences in average vehicle speeds at the visually identified PC and "within curve" locations of the CSAH 3 and CSAH 7 study sites were also calculated. At the CSAH 3 study site these measures were -7.0 and -3.4 mph, respectively. When naively adjusted for the changes in average vehicle speed at the control location, however, the average change in the average vehicle speeds at the CSAH 3 visually identified PC and "within curve" data collection locations are -5.2 and -1.6 mph, respectively. The unadjusted and adjusted differences in average vehicle speeds one month before and 18 months after the installation of the DCWS at the visually identified PC of the CSAH 3 study site were -5.5 mph and -8.6 mph, respectively. At the "within curve" location of the CSAH 3 study site these same measures of average vehicle speed were -1.8 mph and -4.9 mph. Similar calculations for the CSAH 7 study site reveal that the average of the differences in average vehicle speed at the visually identified PC and "within curve" location were -3.0 mph and +0.1 mph, respectively. When naively adjusted for the changes in average vehicle speed at the control location, however, these same measures are -2.6 mph and +1.1 mph, respectively. The unadjusted and adjusted differences in average vehicle speed one month before and 18 months after the installation of the DCWS at the visually identified PC of the CSAH 7 study site were -2.2 mph and +1.9 mph, respectively. At the "within curve" location of the CSAH 7 study site these same measures of average vehicle speed were -2.1 mph and +2.0 mph.

- The potential impact of DCWSs on the percentage of vehicles traveling at or above a particular speed was also investigated. More specifically, the percent change in vehicles traveling 5, 10, 15, and 20 mph more than the posted or advisory (if present) speed limits was calculated. The percentage of vehicles in each category during the "one month before" installation time period was subtracted from the same percentage in each of the "after" installation data collection time periods. The percent change for each time period and overall were also calculated. The results from these calculations generally indicate that the DCWSs appear to have a larger proportional impact on the percentage of vehicles traveling at higher vehicle speeds when compared to those traveling at speeds closer to the posted speed or advisory limits. It is generally accepted that these higher-speed

vehicles are more likely to run off the road or experience difficulties with the proper negotiation of horizontal curves.

- Vehicle crashes at the study sites were just one of the factors considered in the proactive safety improvement prioritization process used to define the candidate study sites for this project. Only those horizontal curves with a high or medium prioritization were considered in this research project. The number of crashes along low-volume roadways (like those in this research), however, is very small. For example, the three study sites selected for this project had only one to five crashes during the five year time period considered in the prioritization. It is also generally acknowledged, however, that the lack of crashes at a low-volume roadway horizontal curve location does not mean that it is "safe". The volumes are so low that the crashes do not occur on a regular basis. A before and after crash comparison was initially proposed for this project, but due to the low number of study sites and crashes it was later removed from the list of tasks. It was concluded that any type of crash comparison within the scope of this project (given the small number of study sites and crashes) would be inappropriate. It was proposed that even the documentation of the number of crashes before and after the installation of the DCWSs would imply that this type of comparison was appropriate when it was not valid. For information purposes, there were no crashes at the CSAH 25, CSAH 3, and CSAH 7 study sites for three years before the DCWS installation (i.e., April 2007 to April 2010) or for the 19 months after. No valid or robust statistical conclusions about the direct impact of the DCWSs on crashes can be made at these study sites. A surrogate measure for safety, in our case the changes in vehicle speed that the visually identified PC and "within curve" locations at each study site, must be used.

Overall Recommendations

- The findings reached by this research study are limited by the number of study sites and the variability of their characteristics. It is recommended that, if appropriate, the results of this research project be combined with those from the national DSFS demonstration study. These combined results should produce more robust implementation recommendations for the DCWS evaluated. Alternatively, the vehicle speed impacts of DCWSs on more low-volume, rural local roadways could be investigated.
- It is recommended that the installation of a DCWS at horizontal curves along low-volume roadways be considered on a case-by-case basis. It would appear that horizontal curves with advisory speed limits well below the posted approach speed limit (e.g., 40 mph) may experience a greater reduction in average vehicle speed at the DCWS location than those with larger advisory speed limits (e.g., 50 mph) or no advisory speed limit posted. Overall, the average of the difference in average vehicle speeds calculated for the DCWS location at each study site (without adjustments for the average vehicle speed changes observed at the control location) were -1.9 mph at CSAH 25, -7.0 mph at CSAH 3, and -3.0 mph at CSAH 7. When naively adjusted for the changes in average vehicle speed at the control locations of each study site these measures change to -2.5 mph at CSAH 25, -5.2 mph at CSAH 3, and -2.6 mph at CSAH 7.

- The characteristics of a horizontal curve impact the need for and the magnitude of an advisory speed limit. As noted above, these characteristics will also likely impact any changes in average vehicle speed at the DCWS (i.e., the visually identified PC) and "within curve" locations that might result from the installation of a DCWS. It is likely that any vehicle speed impacts due to a DCWS will increase on low-volume roadways that also experience a significant number of "unfamiliar" drivers (e.g., a recreational route). This type of roadway, or something similar, may be a good location for the DCWS considered in this research (given its purchase cost, cost of installation, and cost of maintenance). The majority of the drivers at the study sites considered in this research was assumed to be very familiar with the route and may have encountered the DCWS more than once (possibly more than once a day).

- It is recommended that the installation and sign support structure issues described in this report be resolved before this DCWS is considered for installation at similar study sites with the same or similar sign support structure. For example, the DCWSs used at rural locations need to be highly sensitive but they also need to withstand very harsh weather conditions. In all cases, the short-term and long-term impacts of various factors on the stability of the sign support structure need to be considered. The adequacy of the sign support structure used for this research project should be re-evaluated for the DCWS used and similar climatological and geographical study site characteristics. Alternative sign support structures that are more familiar to local highway agencies may be more appropriate for this DCWS. The use of these alternative support structures should reduce installation times and the agencies will be more likely to have the proper installation equipment.

- It is recommended that surrogate measures for safety or crash risk continue to be considered in the selection of safety improvements and the evaluation of countermeasure effectiveness along low-volume roadway locations. In this research the average vehicle speed at the visually identified PC of the horizontal curve was used as a surrogate safety measure. A reduction in the possibility of a crash (e.g., a reduction in approach vehicles speed) is an improvement in the roadway safety at a horizontal curve. It is also recommended that the impact DCWSs may have on the number of vehicles traveling at high speeds be considered when implementing these signs.

- It is recommended that additional research in DCWSs be completed. If necessary, the impact of a DCWS on average truck speed along low-volume roadway may be considered. The number of commercial vehicles at the study sites used in this research project did not allow this analysis. In addition, it recommended that a less costly version of the DCWS considered in this research be designed for low-volume roadway applications. A low cost option is essential to the widespread implementation of this type of sign on low-volume, rural roadways.

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Appendix A

McLeod County Horizontal Curve Review Memorandum

(Attachments Available on Request, Completed by CH2M Hill, Inc., a Subcontractor for this Project)

Background

A site selection process was completed in Freeborn (did not continue with project later), Meeker, and McLeod counties as part of the Minnesota Horizontal Curve Safety Improvement project. The candidate horizontal curves that formed the basis of this process were identified through a prioritization methodology. The curve prioritization in Freeborn and Meeker counties was finished before the start of this project. The approach used and results for these counties are described elsewhere in this document. The McLeod County horizontal curve prioritization was completed by CH2M HILL, Inc. as part of this project. The horizontal curve prioritization methodology used in McLeod County was based on crash characteristics and other geometric factors. It is described below. The curves summarized by CH2M Hill, Inc. were considered candidates for the deployment of a dynamic curve warning sign (DCWS). In some cases, however, the DCWS would be connected to more than one horizontal curve in the list (e.g., two or three horizontal curves in close proximity signed as with a winding curve sign, W1-5). This type of situation was confirmed through site visits.

McLeod County experienced 2,929 crashes between 2003 and 2007. Eighty-seven of these crashes were severe (i.e., fatal or A-injury). Almost three-quarters of these severe crashes (n = 63 or 72%) occurred in rural areas (Note: rural is defined through Minnesota's Crash Mapping Analysis Tool (not being coded to a city)). A road departure was listed as the most common crash type and accounted for 37% (n = 23) of these severe rural crashes and 32% of all rural crashes (n = 415). A larger percentage of the severe road departure crashes (n =-10 or 44%) along rural highways were horizontal curve-related. The same pattern was also found for all rural road departure crashes. Approximately 30% of these crashes were curve-related.

A review of the McLeod County map found 242 horizontal curves along 41 County Highways (CSAH) and County Roads (CR). Only one curve, along CSAH 2 near Glencoe, MN averaged more than one crash per year. It experienced 8 crashes during the 5-year study period. The majority of curves (n = 178 or 74%) did not experience a single crash. On average, all 242 horizontal curves experienced about 0.08 crashes per curve per year. A comprehensive list of these horizontal curves can be found in **Attachment A** (available on request).

Horizontal Curve Prioritization Methodology

The methodology used to prioritize the 242 horizontal curves identified along McLeod's county highway system included three factors. The three criteria of interest consisted of the horizontal curve crash experience from 2003 to 2007, estimated radius, and the presence or absence of a visual trap. This methodology applied is identical to the process previously used to prioritize curves in Freeborn County and similar to that used in Meeker County. A detailed description of the selection criteria follows.

1) Crashes: The Minnesota Crash Mapping Analysis Tool (MnCMAT) was used to identify the number and characteristics of the crashes that occurred along the horizontal curves identified. As indicated previously, horizontal curves were identified for consideration in this project based on a review of the county highway map. The horizontal curves with any previous crash experience were identified as a higher priority candidate for safety improvements.

2) Horizontal Curve Radius: Recent research published by the Texas Transportation Institute (Reference: Bonneson, J., M. Pratt, J. Miles, and P. Carlson. *Development of Guidelines for Establishing Effective Curve Advisory Speeds*. FHWA/TX-07/0-5439-1. Texas Department of Transportation, Austin, Texas. October 2007.), as well as highway safety plans for Minnesota Department of Transportation (Mn/DOT) Districts 3 and 7, demonstrated that for rural highways (with a 55 mph speed limit) the expected fatal and injury crash rate increases as the horizontal curve radius decreases. **Figure 1** illustrates how the expected fatal and injury rates calculated in *Texas and Minnesota (i.e., Mn/DOT Districts 3 and 7 and Freeborn County) increase* dramatically at a radius of approximately 800 feet. **Figure 2** also shows an increase in overall horizontal curve crash rate for facilities with radii less than 1,000 feet along Mn/DOT District 3 and 7 state roadways. During the prioritization process, therefore, horizontal curves with an estimated radius less than 800 feet were considered to be a higher safety improvement priority. *Note: Curve radius was estimated using Google Earth.*

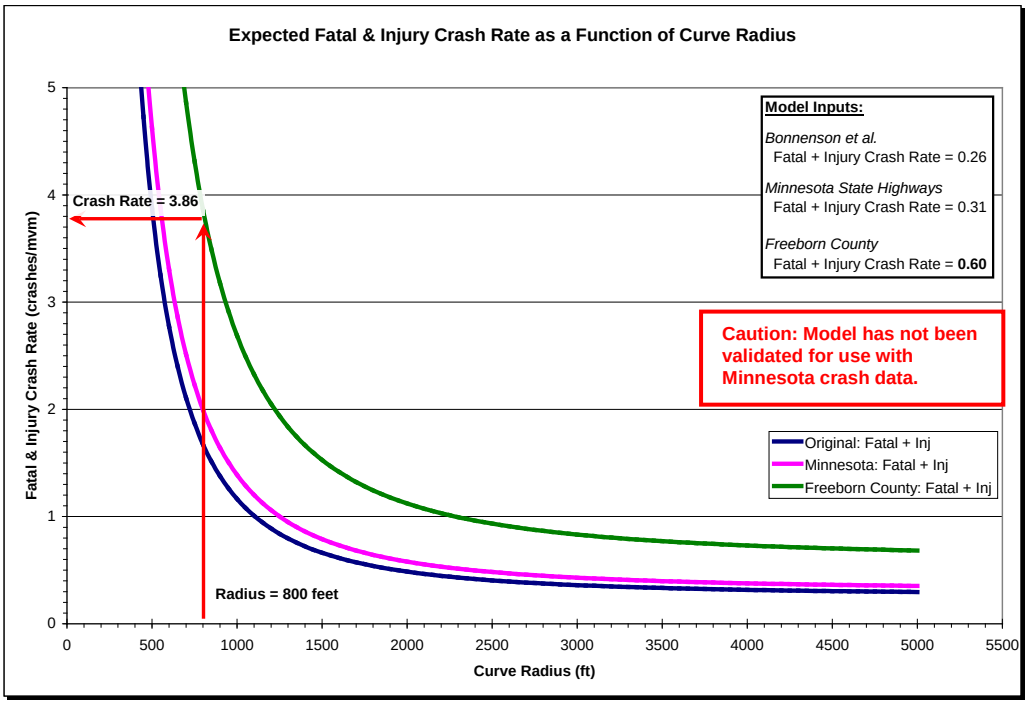

Figure 1. Predicted Curve Fatal and Injury Crash Rate as a Function of Curve Radius

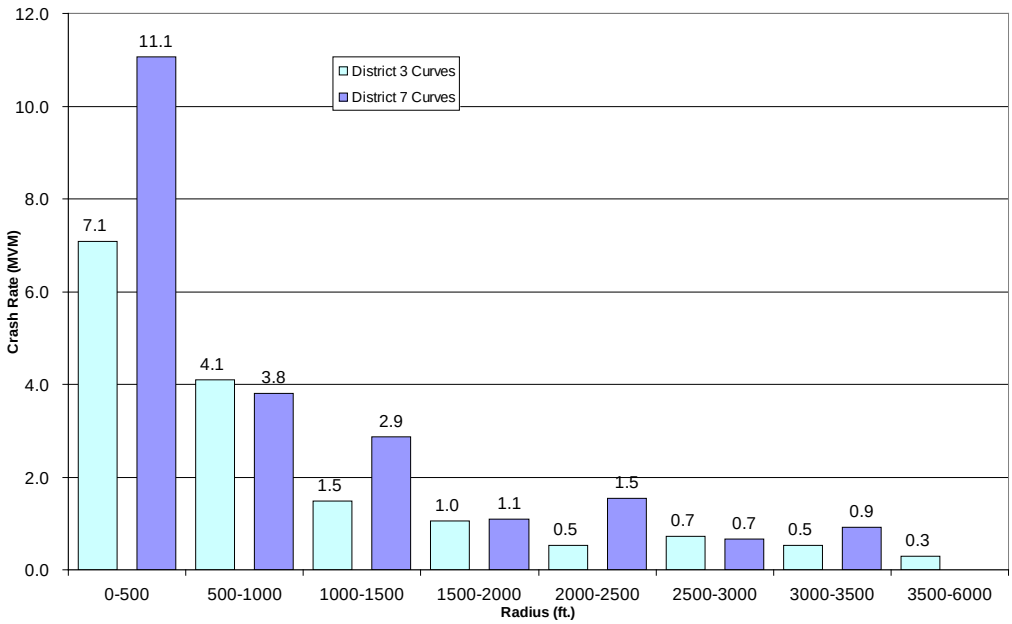

Figure 2. Curve Crash Rate by Radius for Mn/DOT District 3 and District 7

3) Visual Trap: The third factor considered in the horizontal curve prioritization was the presence or absence of a visual trap. One example of a visual trap is a horizontal curve that follows a crest vertical curve. In this case the approaching driver cannot see the horizontal curve in advance. A visual trap can also occur where a township road, utility pole, fence line with trees, etc. extends straight, but the county highway curves. This situation gives the perception to the driver that the road is likely straight. Two examples of visual traps are shown in **Figure 3**. Curves identified as having a visual trap condition were considered to have a higher safety improvement priority.

Figure 3. Examples Visual Traps (Locations in McLeod County)

The 242 horizontal curves identified in McLeod County were ranked as high, medium, or low priority for potential safety improvements unless there chevrons already in-place. However, the horizontal curves with chevrons were still considered potential candidates for DCWS implementation in this project. The specific requirements of each priority classification are documented below:

High Priority

- Horizontal curve had a visual trap on one or both approaches, or
- Horizontal curve radius was equal to or less than 800 feet and had at least one crash from 2003 to 2007, or
- Horizontal curve was located on a corridor where other horizontal curves already had additional delineation installed (e.g., chevrons).

Medium Priority

- Horizontal curves where a crash had occurred from 2003 to 2007, or
- Horizontal curve radius was equal to or less than 800 feet.

Low Priority

- Horizontal curves where no crash was recorded, and
- Horizontal curve radius greater than 800 feet, and
- Horizontal curve location did not have a visual trap on one or both approaches.

Each horizontal curve was given a unique identifier (See example **Figure 4)** and located in the list and on the map in **Attachment B** (available on request). For example, Curve 1-1 is located along CSAH 1 and is the first horizontal curve from the north border of McLeod County. Figure 4 shows that Curve 1-1 does not have a visual trap or a radius equal to or less than 800 feet. Curve 1-1, however, is located on a corridor where other curve(s) have additional delineation "in-place" (i.e., Curve 1-3) and is ranked with a high safety improvement priority.

Map #	CSAH/CR	#	From	To	Curve #	K (0)	A (7)	B (13)	C (22)	PD (59)	Radius	Visual Trap	ADT	Chevrons in Place	Final Ranking	Notes
1-1	CSAH	1	Wright County Line	Sibley County Line	1	-	-	2	-	2	1,100	-	2,900	-	High	
1-2	CSAH	1	Wright County Line	Sibley County Line	2	-	-	-	-	1	1,550	-	2,900	-	High	
1-3	CSAH	1	Wright County Line	Sibley County Line	3	-	-	-	-	1	750	Yes	2,000	Yes	In-Place	
1-4	CSAH	1	Wright County Line	Sibley County Line	4	-	-	-	-	3	1,400	Yes	1,775	-	High	
2-1	CSAH	2	MN 7	Wright County Line	1	-	-	-	1	-	500	Yes	1,350	-	High	
2-2	CSAH	2	MN 7	Wright County Line	2	-	-	-	-	-	950	-	1,350	-	Low	
2-3	CSAH	2	MN 7	Wright County Line	3	-	-	-	-	-	900	-	1,350	-	Low	
2-4	CSAH	2	MN 7	Wright County Line	4	-	-	-	-	1	950	-	1,350	-	Medium	

Figure 4. Data for Curves Along CSAH 1 and CSAH 2

Existing chevrons were identified at 65 of the 242 horizontal curves identified along the McLeod County roadways. These locations were identified with information from the County Engineer and the results of a field visit. An example of a location with chevrons "in-place" is shown in **Figure 5**.

Figure 5. Chevrons Installed Along CSAH 19 at Curve 11 (Curve 19-11)

Overall, approximately one-third (n = 60) of the horizontal curves without chevrons received a high priority ranking (See Figure 6). In addition, about 44% (n = 78) of the horizontal curves without chevrons were ranked as medium priority and 22% (n = 39) as low priority. A summary of the number and percentage of horizontal curves by priority ranking is noted in **Figure 6**.

	Curve Count	All Curves	Curves w/o Chevrons
High	60	25%	34%
Medium	78	32%	44%
Low	39	16%	22%
In-Place	65	27%	
All Curves	242		
Curves without Chevrons	177		

Figure 6. Summary of Curve Priority Ranking

High Priority Horizontal Curves

A list of the 60 curves assigned a high priority ranking is shown in **Figure** 7 and Attachment D. These 60 high priority horizontal curves represent a subset of the curves that were considered candidates for the deployment of the DCWS (based on crash history and geometric characteristic). A categorized list of assigned priority or "in-place" status for all 242 horizontal curves is shown in **Attachment C** (available on request). The horizontal curves assigned a medium priority, with one or *more* crashes, were also considered in the project site selection. The horizontal curves that met this requirement but also had chevrons "in-place" were also considered.

Map #	CSAH/CR	#	From	To	Curve #	Final Ranking
1-1	CSAH	1	Wright County Line	Sibley County Line	1	High
1-2	CSAH	1	Wright County Line	Sibley County Line	2	High
1-4	CSAH	1	Wright County Line	Sibley County Line	4	High
2-1	CSAH	2	MN 7	Wright County Line	1	High
2-8	CSAH	2	Silver Lake City Limits	Glencoe City Limits	8	High
2-10	CSAH	2	Silver Lake City Limits	Glencoe City Limits	10	High
2-11	CSAH	2	Silver Lake City Limits	Glencoe City Limits	11	High
2-12	CSAH	2	Silver Lake City Limits	Glencoe City Limits	12	High
2-13	CSAH	2	Silver Lake City Limits	Glencoe City Limits	13	High
3-6	CSAH	3	MN 15	Glencoe City Limits	6	High
4-3	CSAH	4	CSAH 7	MN 7	3	High
4-4	CSAH	4	CSAH 7	MN 7	4	High
7-1	CSAH	7	Sibley County Line	CSAH 8	1	High
7-2	CSAH	7	Sibley County Line	CSAH 8	2	High
7-3	CSAH	7	Sibley County Line	CSAH 8	3	High
7-5	CSAH	7	Sibley County Line	CSAH 8	5	High
7-6	CSAH	7	Sibley County Line	CSAH 8	6	High
7-7	CSAH	7	Sibley County Line	CSAH 8	7	High
7-8	CSAH	7	Sibley County Line	CSAH 8	8	High
7-10	CSAH	7	Sibley County Line	CSAH 8	10	High
7-11	CSAH	7	Sibley County Line	CSAH 8	11	High
7-14	CSAH	7	Hutchinson City Limits	Meeker County Line	14	High
8-2	CSAH	8	Renville County Line	CSAH 7	2	High
8-3	CSAH	8	Renville County Line	CSAH 7	3	High
8-4	CSAH	8	Renville County Line	CSAH 7	4	High
8-5	CSAH	8	Renville County Line	CSAH 7	5	High
8-6	CSAH	8	Renville County Line	CSAH 7	6	High
9-1	CSAH	9	Winsted City Limits	Plato City Limits	1	High
9-5	CSAH	9	Winsted City Limits	Plato City Limits	5	High
9-6	CSAH	9	Winsted City Limits	Plato City Limits	6	High
9-8	CSAH	9	Winsted City Limits	Plato City Limits	8	High
9-9	CSAH	9	Winsted City Limits	Plato City Limits	9	High
9-10	CSAH	9	Winsted City Limits	Plato City Limits	10	High
12-2	CSAH	12	Meeker County Line	CSAH 7	2	High
15-3	CSAH	15	MN 7	Glencoe City Limits	3	High
16-5	CSAH	16	Wright County Line	MN 7	5	High
16-6	CSAH	16	Wright County Line	MN 7	6	High
24-4	CSAH	24	CSAH 11	CSAH 2	4	High
24-5	CSAH	24	CSAH 11	CSAH 2	5	High
24-6	CSAH	24	CSAH 11	CSAH 2	6	High
25-3	CSAH	25	Brownton City Limits	CSAH 8	3	High
52-3	CR	52	US 212	CSAH 13	3	High
52-4	CR	52	US 212	CSAH 13	4	High
52-5	CR	52	US 212	CSAH 13	5	High
54-1	CR	54	CSAH 7	CSAH 17	1	High
60-11	CR	60	MN 15	CSAH 16	11	High
60-17	CR	60	MN 15	CSAH 16	17	High
60-18	CR	60	MN 15	CSAH 16	18	High
60-19	CR	60	MN 15	CSAH 16	19	High
60-20	CR	60	MN 15	CSAH 16	20	High
61-3	CR	61	CR 79	CR 60	3	High
62-2	CR	62	CSAH 25	CSAH 4	2	High
65-3	CR	65	Sibley County Line	CSAH 3	3	High
65-5	CR	65	Sibley County Line	CSAH 3	5	High
74-3	CR	74	CSAH 15	CSAH 3	3	High
79-3	CR	79	CSAH 7	CSAH 4	3	High
79-12	CR	79	CSAH 7	CSAH 4	12	High
85-4	CR	85	Winsted City Limits	Carver County Line	4	High
86-4	CR	86	CSAH 2	CSAH 5	4	High
86-5	CR	86	CSAH 2	CSAH 5	5	High

Figure 7. McLeod County High Priority Curves

Appendix B

Meeker County Final Candidate Horizontal Curve Study Sites

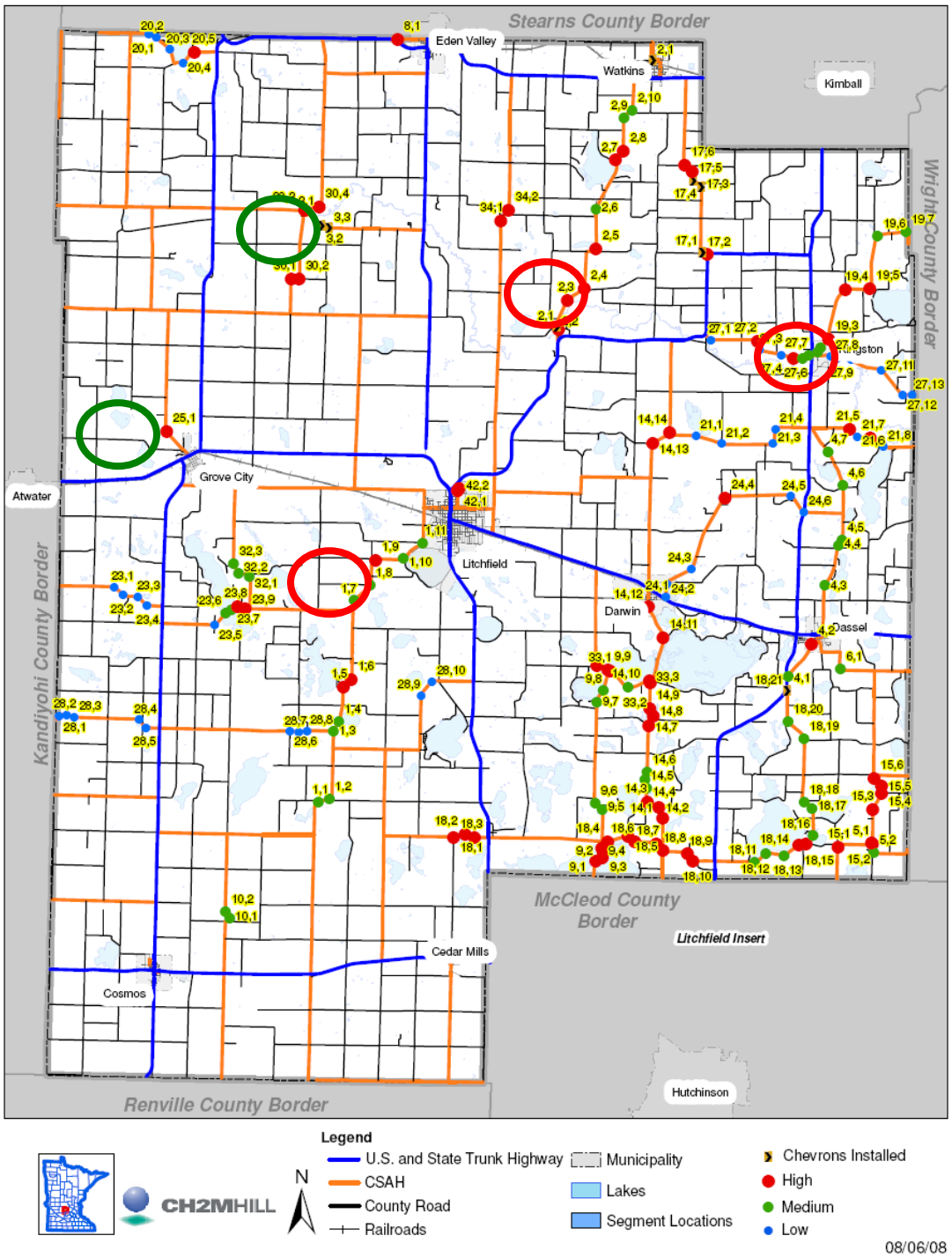

Figure B-1. Meeker County Preliminary Speed Data Collection Sites (*35*)

Appendix C

McLeod County Final Candidate Horizontal Curve Study Sites

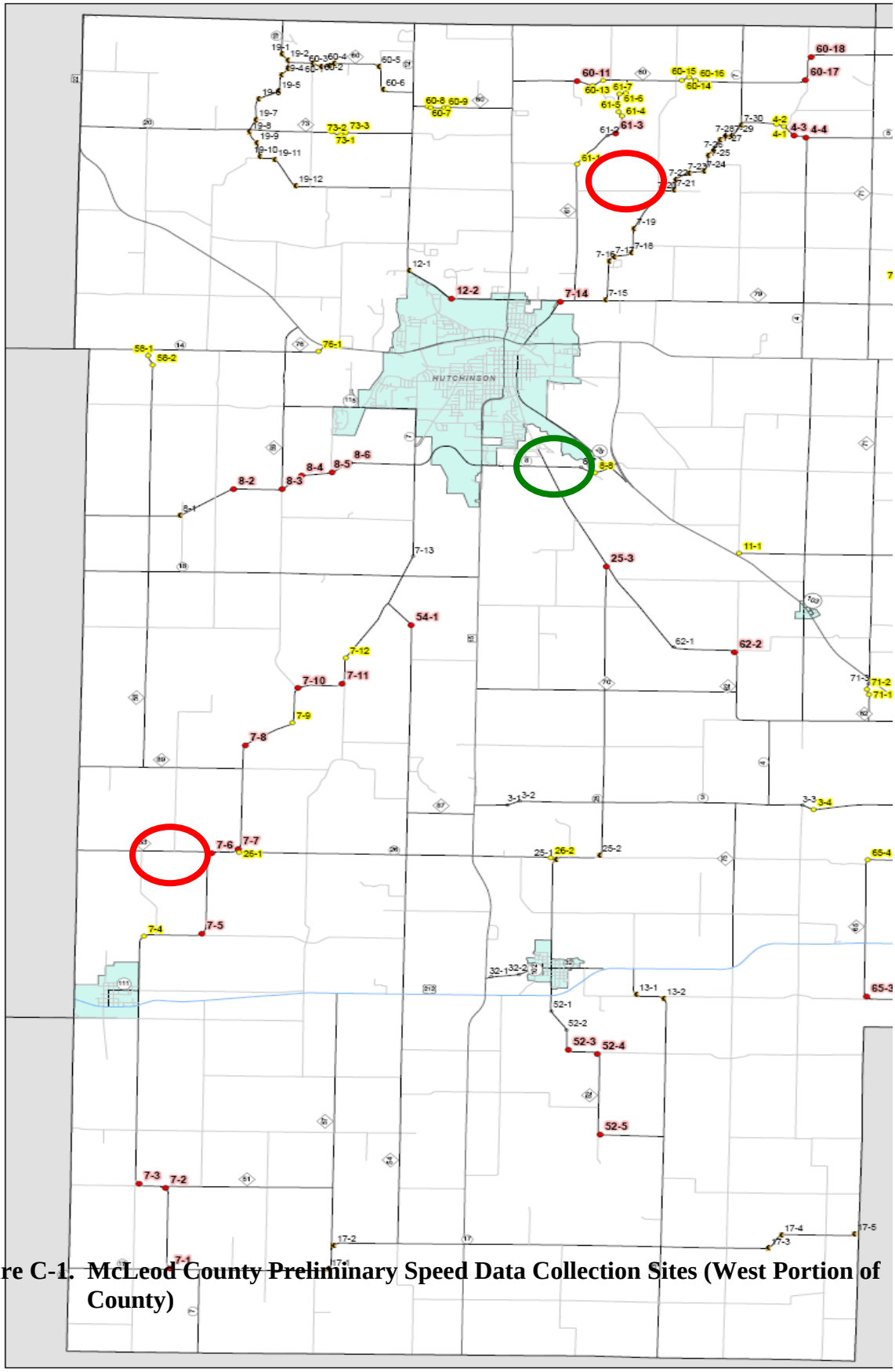

Figure C-1. McLeod County Preliminary Speed Data Collection Sites (West Portion of County)

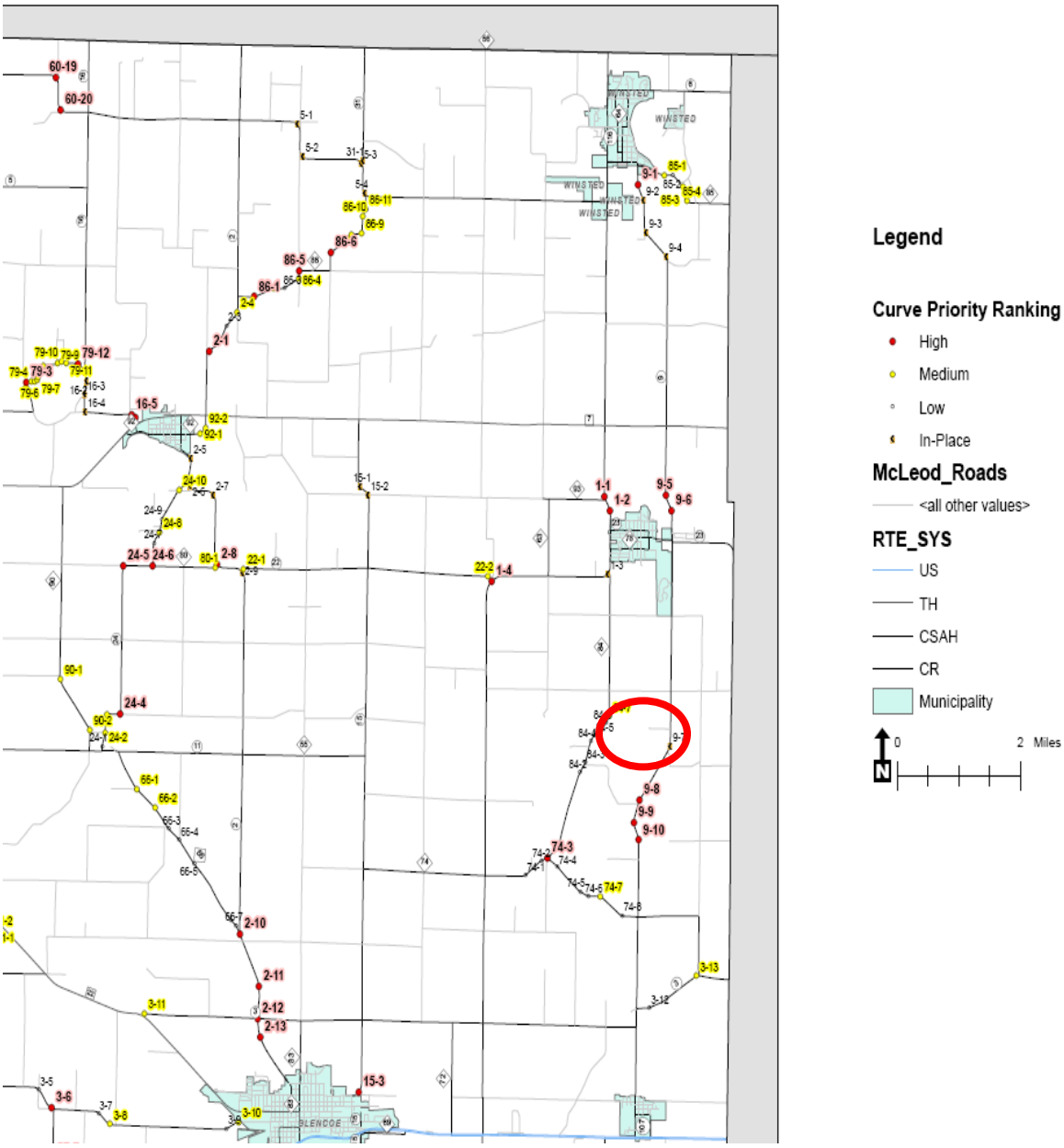

Figure C-2. McLeod County Preliminary Speed Data Collection Sites (East Portion of County)